WATER

AND

WATER SUPPLIES

BY

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PREFACE

(TO THE THIRD EDITION).

A THIRD edition of this work being called for, the publishers have kindly afforded me the opportunity of bringing it up to date, and of including additional chapters on the Protection of Water Supplies.

I have to thank many Medical Officers of Health and Waterworks Engineers for the verification of statements and for information furnished.

The legal portion has been revised by my friend, Mr. John C. Freeman, Clerk to the Maldon Rural District Council, and my thanks are due to him for his valuable assistance.

I have also to thank my assistant, A. E. Porter, M.D., D.P.H., and my late assistant, R. W. C. Pierce, M.B., D.P.H., now Medical Officer of Health for the Guildford District, for revising the proofs and assisting me generally in preparing this edition for the press.

JOHN C. THRESH.

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WATER SUPPLIES.

CHAPTER I.

WATER, ITS COMPOSITION, PROPERTIES, ETC.

FROM the time of Aristotle until the close of the eighteenth century, water was regarded as an elementary substance,—that is, one which could not be split up or decomposed into any simpler forms of matter. In 1781 an English chemist, Henry Cavendish, discovered that when two gases, oxygen and hydrogen, were mixed together in certain proportions (two of hydrogen to one of oxygen) and an electric spark passed through the mixture, combination took place and water was formed. Many other ways have since been devised for causing these gases to combine and for demonstrating that water is the product formed. By other methods also water can be decomposed and made to yield the two elements which alone enter into its composition when pure. For example, if a strong current of electricity be passed through water, bubbles of gas are given off from each terminal or pole. At the one pole the gas consists of pure oxygen, at the other of pure hydrogen, and the volumes obtained are two of the latter to one of the former. As oxygen is sixteen times as heavy as hydrogen, the composition of pure water is as under:—

	By Volume.	By Weight.
Oxygen . . .	1 part . .	8 parts.
Hydrogen . . .	2 parts . .	1 part.

Pure water is a chemical curiosity. The moisture which bedews the tube in which the mixture of hydrogen and oxygen has been exploded is water in its purest form. If, however, it be exposed to the air or be allowed to stand in contact with any substance (save perhaps some of the less oxidisable metals, as platinum and gold) it will absorb gases from the air or dissolve some of the material of the vessel in which it is placed, and from a chemical point of view is no longer pure. Pure water does not occur in nature, even rain water caught in mountainous districts far from the smoke of towns or the haunts of men contains traces of impurities taken up from the air. When the foreign substances are present in so small quantities as not appreciably to affect the physical properties of the water, or to render it unfit for domestic and manufacturing purposes, it is popularly spoken of as "pure," and it is in this sense that the term "pure water" will in future be used throughout this book.

Pure water, when viewed in small quantities, appears to be perfectly colourless, but when viewed in bulk, as in the white tiled baths at Buxton, and in certain Swiss lakes, it is seen to possess a beautiful greenish-blue tint. A very small amount of suspended or dissolved impurity is sufficient to obscure this colour. Impure waters almost invariably exhibit a colour varying from green to yellow and brown when examined in suitable tubes about two feet in length, but, as will be seen later, it does not always follow that a water with a brownish tint is too impure for domestic use. Pure water is absolutely devoid of odour and is destitute of taste. The purest is insipid, but if such a water be aerated by agitation with air or by filtration through a porous, air-containing medium, the insipidity disappears. Practically, water is incompressible, but the volume of a given weight varies very considerably with the temperature. With very few exceptions all fluids expand when heated and contract when cooled. The most important exception is water between

certain temperatures. As the effect of heat upon water has a direct bearing upon certain points connected with water supplies, it is necessary briefly to consider the action of change of temperature. If a quantity of pounded ice, with a little water, be placed in a glass beaker in which two thermometers are placed, one at the bottom and the other near the surface of the mixture, it will be found that both indicate the same temperature, 0° C. If now some source of heat be applied to the beaker, it will be observed that neither thermometer will indicate any increase of temperature until the last particle of ice is melted. The heat, as such, has disappeared, its effect upon the ice being not to raise its temperature but to liquefy it. The same fact can be proved by another simple experiment, which enables us also to measure the amount of heat which disappears or becomes latent. If one pint of water, at the temperature of 0° C., be mixed with one pint of water at 79° C., the temperature of the mixture will be the mean, 39.5° C. If, however, ice at 0° C. be substituted for the cold water, the whole of the ice will melt, but the temperature of the resulting fluid will not be 39.5° C. but 0°. Water at 0°, *i.e.* at its freezing point, may be said to be ice plus heat. This heat, which becomes latent during the process of liquefaction, is again given off when water freezes. As the surface of a sheet of water freezes, the water, in the act of solidification, gives up a certain amount of heat. This raises the temperature of the remaining water, and so the process of freezing or solidification is retarded. Were not this the case, during winter water would freeze with great rapidity, and the ice so formed would as rapidly melt when the weather became warmer. Such a condition of things would render all but the tropical and sub-tropical regions practically uninhabitable during certain portions of the year. As soon as the temperature sank below zero, ice would so quickly form that our lakes, reservoirs, streams, etc., would

contain only solid ice. Snows would melt so rapidly with a slight increase of temperature that most disastrous floods would follow. This sudden freezing also would result in the bursting of every water main and pipe, since water in the act of solidification expands considerably, eleven pints of water when frozen forming twelve pints of ice, or, in other words, water expands one-eleventh of its volume in the act of freezing. The effects of this expansion are disastrous enough to water mains and pipes when the freezing process is retarded by the heat given off by the water as it solidifies; but if the solidification took place suddenly, as soon as the temperature fell slightly below zero, the expansion, being uniform in every direction, would burst every pipe or vessel in which the water was contained. The force so exerted in the act of freezing is enormous. Thick iron shells filled with water and securely plugged are easily burst by exposure to the cold of a Canadian winter's night.

Water is at its maximum density at 4° C. If cooled below that temperature it expands; if the temperature is raised it also expands. It thus differs from nearly all other liquids, which at all temperatures between their freezing and boiling points expand when heated and contract when cooled. If a jar of water be exposed to a temperature below zero, and two thermometers are placed in the water, one at the bottom and the other near the surface, it will be found that the thermometer at the bottom records a continuously lower temperature than the one near the surface until 4° C. is reached. Up to this point the colder water, being heavier, has continued to fall to the bottom of the jar. Below this temperature the upper instrument will record the lower temperature, proving that at temperatures below 4° water becomes specifically lighter. If such were not the case the water at the bottom of the vessel would continue the colder and would be the first to freeze. Solidification would take place from below upwards. The result would be that during a severe winter our streams and lakes

would become one mass of ice, which all the heat of the ensuing summer would be unable to melt. To quote Professor Roscoe, "If it were not for this apparently unimportant property our climate would be perfectly arctic, and Europe would in all probability be as uninhabitable as Melville Island." As it is, in large lakes and rivers the temperature of the deep water never falls below 4° during the winter, and the surface water when cooled to zero begins to freeze, and at the same time to liberate its latent heat, which raises the temperature of the layer beneath, and so retards the cooling process. That the habitability of such a large portion of the globe should depend upon these exceptional properties is a remarkable fact.

At the sea-level mean barometric pressure (760 mm.) water boils at 100° C. When the atmospheric pressure is decreased, as in ascending a mountain, or when the water-containing vessel is placed under the receiver of an air pump and a portion of the air exhausted, the boiling point is lowered. On the summits of the highest mountains water boils at so low a temperature that meat cannot be thoroughly cooked in it, and in the vacuum produced by a properly-constructed air pump water can be made to boil rapidly at ordinary temperatures, and as during evaporation heat is lost, the temperature is reduced so low that the water freezes as it boils. If boiled in an open vessel water rapidly and visibly evaporates, but this evaporation takes place invisibly at all temperatures, the more slowly the lower the temperature. Even snow and ice slowly disappear by evaporation during winter. The rate of evaporation from an exposed surface depends upon several factors, the more important being the temperature, the velocity of the air in contact with the surface, and the dryness of the air. On a dry, hot, windy day, evaporation is rapid; on a damp, cold, calm day evaporation approaches its minimum. The bearing of these facts upon the subject of rainfall and the storage of water will be discussed in subsequent chapters.

Water has remarkable solvent powers. The number and variety of substances which it can take into solution greatly exceed that of any other fluid. Some substances, such as sugar and salt, it dissolves in large quantities and with considerable rapidity; others, such as the constituents of most rocks, it only dissolves in small quantity and very slowly. Many gases, such as ammonia and hydrochloric acid, it absorbs with avidity, taking up many times its own volume; others, such as nitrogen and oxygen, the two principal constituents of the atmosphere, it only dissolves in small proportions; whilst of others, such as carbonic acid, it can dissolve about its own volume. This property of absorbing or dissolving gases is a most important one. It explains how water may become contaminated by mere exposure to an impure atmosphere, as when an uncovered cistern is placed in a water-closet, or when an overflow pipe is directly connected with a drain. One of the most important constituents of nearly all natural waters is carbonic acid gas. This gas is always present in the air, and all rain waters contain some of it, but still more is taken up by the water as it percolates through ground covered with vegetation. The presence of this gas increases the solvent powers of the water, enabling it to dissolve carbonate of lime (chalk and limestone) and carbonate of magnesia very freely. If a sample of tolerably "hard" water be placed in a flask and gently heated, bubbles of gas will be observed to form in the water, rise to the surface and burst. These bubbles are the gases (oxygen, nitrogen, and carbonic acid) which were previously held in solution by the water. The carbonic acid, being most soluble, is not wholly given off until the water boils. As this gas is removed the water will become more or less turbid from the deposition of minute solid particles of carbonate of lime or of this substance with carbonate of magnesia. One gallon of pure water will only dissolve from two to three grains of these carbonates, but when the water contains carbonic acid it may dissolve twenty or more

grains. The whole of this excess is thrown out of solution if the water be boiled so as to expel the acid. If the water now be filtered or decanted from the deposited solid matter, and again boiled until the whole has evaporated, a greyish-white residue will be found on the bottom of the vessel. This consists of the mineral (and possibly some organic) substances which the water had held in solution. The amount will vary with the character of the water. Rain water leaves a very slight residue, whilst that yielded by sea water is very abundant indeed. If this residue be free from organic matter (usually derived from decaying animal or vegetable substances), it will undergo little or no change in colour when heated to redness; whereas, if organic impurity be present, it will char when heated, the residue becoming brown or even black.

The common constituents of natural waters may be classified as follows:—

GASEOUS.		Carbonic acid, oxygen, and nitrogen.
SOLIDS.	(*a*) *Mineral.*	Carbonates of lime and magnesia.
		Sulphates of lime, magnesia, and soda.
		Chloride of sodium (common salt).
	(*b*) *Organic.*	Products of decomposition of animal and vegetable matter.

Besides the matters in solution many waters contain others in suspension, and these again may be divided into inorganic (mineral), such as clay, fine sand, débris of rocks, etc., and organic, such as the lower forms of animal and vegetable life, living or dead. The nature of the mineral constituents will be more fully discussed in the chapters relating to waters from different sources, and the organic impurities in the section devoted to the quality of waters.

Waters containing very small quantities of lime and magnesia salts are called "soft," since they lather freely with soap, whilst waters containing larger quantities are termed "hard," since they form a curd with soap, a more or less considerable quantity of the soap being wasted in

decomposing the lime and magnesia compounds before a lather will form. The hardness is usually expressed by chemists in degrees, each degree corresponding to one grain of carbonate of lime, or its equivalent of other lime or magnesia salts in the gallon of water. As previously stated, the carbonates are thrown out of solution by boiling, and the water then becomes softer in proportion to the amount of these salts so removed. This removable hardness is called "temporary," whilst the hardness remaining after boiling, and which is chiefly due to the presence of sulphates of lime and magnesia, is called "permanent." Waters under 5° or 6° of hardness may be considered "soft," those exceeding 12° "hard." The advantages and disadvantages of "soft" water will be fully discussed later, when all the points bearing upon the selection of a source of supply are being considered.

Water not only takes up gases from the air, mineral and organic matter from rocks and soil, but certain waters act upon and dissolve traces of the metals—lead, iron, and zinc—of which cisterns and pipes are generally made. A chemically pure water would probably have no action whatever upon these metals if also chemically pure; but as natural waters are never absolutely pure, nor the metals free from impurities, under certain conditions chemical or electrolytic action is set up, and the metals are acted upon. The presence of any of these metals in a drinking water is objectionable, but traces of lead are far more dangerous than traces of iron or zinc, since lead is not only more poisonous, but is also a cumulative poison—that is, the lead tends to accumulate in the system, and as the quantity stored increases so also does its poisonous action become more marked. The medical officer to the Local Government Board, in his report for the year 1890, stated that "upwards of 600,000 persons in the West Riding of Yorkshire alone appear, from the statements of medical officers of health, to be at one or another time liable to

lead-poisoning by the drinking-water supplied to their populations." The districts of Lancashire and West Yorkshire appear to suffer more than others from this form of poisoning, and certain medical inspectors were deputed to conduct such "chemical and bacteriological" studies as were most likely to lead to the discovery of the conditions under which waters can acquire the power of dissolving lead. Unfortunately the cholera scare interfered with the investigation, and it is not yet completed. Dr. Sinclair White found that all the waters he examined which acted upon lead were distinctly acid, and at Sheffield the solvent action of the water varied directly with the acidity. When this acidity was neutralised in any way, as by the addition of limestone (carbonate of lime), or carbonate of soda, the water no longer attacked the metal. He believes that the acid is derived from the decaying peat on the moors upon which the water is collected. Other observers think that the acidity is due to sulphuric acid, which is present in the air in immense quantities in districts where certain iron and other ores are smelted, and where inferior kinds of coal (containing pyrites) are consumed. Assuming it to be true that the rain can in this manner acquire some degree of acidity, it may be questioned whether it is ever possible for it to acquire an amount of acid in any way comparable with the extreme amount found to be present in certain moorland waters. Moreover, the gathering grounds yielding the most acid waters are by no means always situated the most closely to such manufacturing areas.

Others, again, believe that the acidity of moorland waters arises from the slow oxidation of iron pyrites in the soil. That iron pyrites, in the presence of oxygen and moisture, forms sulphuric acid is of course a fact familiar to all chemists. But it may be doubted whether the distribution of iron pyrites on moorland gathering grounds is such as to render this explanation a generally applicable one.

The comparative absence of silica and carbonate of lime has been suggested as the cause of the action of moorland waters on lead, but it is tolerably certain that there are accompanying factors, and that the absence of these substances bears no direct causal relationship to plumbo-solvency.

Mr. W. H. Power, as far back as 1888,* suggested that as chemistry had signally failed to give us a clear insight into the antecedent cause of the acidity of moorland waters, the study of the question from the biological point of view might prove of service.

Again, in 1895,† Mr. Power pointed out that his original forecast had in great measure been confirmed by the labours of the experts employed by the Local Government Board to study the question. In summarising the work done up to the time of writing his report, Mr. Power drew attention to the following facts and inferences: Moorland waters when they have left the moor, when they have become divorced as it were from the peat, have completed their history so far as acidity is concerned. Thus the storage of such waters under a variety of conditions never leads to any increase of acidity, and usually there is an appreciable decrease. Moist peat soil is invariably acid in reaction, and certain microbes isolated from peat possess the power when grown in a neutral decoction made *solely from peat* of rendering the liquid acid and giving it as well plumbo-solvent ability. The inference is that the acidity and plumbo-solvent ability observed in moorland waters is possibly (if not probably) to be traced to the washing out of the products of the life processes of these bacteria from the substance of peat soil. Further, Mr. Power laid considerable stress on the value of the observations carried

* Supplement by the medical officer to the seventeenth Annual Report of the Local Government Board, 1888.

† Report of the medical officer, Local Government Board, 1893-4. "Lead Poisoning by Moorland Waters," by W. H. Power, F.R.S.

out on the Burnmoor moorland gathering ground in their negative aspects. Thus he says: "They (*i.e.* the Burnmoor observations) tend to indicate, by a plurality of determinations spread over many months, not only that the ability of a particular water to dissolve lead is closely associated with acidity of such water, but also that this action in regard of lead *is not to be* so associated with any other observed condition to which the water was liable." Dr. Scatterty, M.O.H., Keighley (Public Health, April, 1895), also pointed out this acid-producing property of peat, and referred to the acid so produced as the cause of the plumbo-solvent action of moorland waters.

Dr. Garrett, as the result of a long series of experiments, considers the action as "primarily an oxidising one," dependent upon the presence of nitrates or nitrites. A very minute quantity of these substances, he says, appears capable of setting up this action, which is further assisted by the presence of chlorides. Acid waters freely dissolve oxide of lead so formed, hence "the power exhibited . . . by waters of acid reaction, of taking lead into solution when they are placed in contact with the metal, is easily explained." Whatever may be the nature of the action which takes place, the waters which act most freely on lead are "soft" waters, such as rain water, upland surface-water, and the waters of certain lakes; and if the uplands from which the water is collected be covered with peat, the plumbo-solvent action of the water will at certain seasons be most energetic. Certain hard waters from the Bagshot Sands act upon lead, but all those which I have examined either contained no carbonate of lime, or less than three grains per gallon—that is, the hardness was entirely, or almost entirely, of a "permanent" character. Certain exceptionally soft deep-well waters found in Essex have no action upon lead, but though almost free from carbonate of lime, they contain a considerable amount of carbonate of soda,

which renders the water alkaline, and so produces the same effect as the carbonate of lime. The introduction into any water of four or five grains of carbonate of lime per gallon (as by filtration through beds of chalk or limestone), or its equivalent of carbonate of soda, effectually prevents any action upon lead; not only so, but such waters cause the formation of a deposit upon the surface of the metal of some compound, which resists for a time the action of the untreated water.

Whilst the presence of lead can only be discovered by the application of chemical tests to the water, or surmised from the symptoms of lead poisoning amongst those who use it (since it affects neither the taste nor appearance), the presence of iron derived from the action of the water upon a pipe or cistern is detected at once by the water exhibiting a more or less marked turbidity and depositing upon standing a little rust-coloured sediment. The amount of iron actually in solution is always infinitesimal, the compound of iron formed by the action of the water (or its gaseous and saline constituents) upon the metal being practically insoluble, and if filtered such water is in no way deleterious to health. The unfiltered water, however, has an unsightly appearance (from the suspended oxide) and will iron-mould clothes if used for washing. The action diminishes after a time as the pipes become coated with oxide, but probably never entirely ceases. As this action can be entirely prevented by using pipes or cisterns coated inside with some "protective" (*vide* Chapter XXI.), such should always be used.

Waters which act on lead appear also to have the power of acting upon zinc, and of forming poisonous compounds which dissolve freely in the water. As the physical characters of the water are not altered, the presence of the metal may remain unsuspected, unless some obscure form of illness leads the medical attendant to have it examined. When water which contains an appreciable amount of zinc

is heated in an open vessel, before it commences to boil an iridescent film is observed upon the surface, sometimes giving rise to the impression that the water is "greasy." Waters acting upon zinc should not be stored in zinc or galvanised iron vessels, or passed through galvanised iron pipes. In a few instances I have come across waters which had an appreciable action upon copper, and cases are recorded of water used for domestic purposes corroding brass fittings and becoming contaminated with the constituents of the alloy.

Waters containing no deleterious organic matters, and only such mineral matters as neither from their quality nor quantity are objectionable, may be considered as pure from the hygienic point of view. If the mineral matters are in excess, or deleterious or objectionable organic substances are also present, the water is impure. Where the mineral constituents are, either from their quantity or quality, sufficiently potent to confer medicinal qualities upon the water, it is called a mineral water. Such waters, if containing iron, are "ferruginous" or "chalybeate"; if containing odorous sulphur compounds, "sulphuretted"; if containing sulphate of magnesia or other mild purgatives, "aperient," etc. These waters are, of course, useless for domestic purposes, and therefore require no further reference here.

Potable waters may be divided into the following classes, according to the source from which they are directly obtained:

Rain water.
Surface water (including lake and pond waters).
Subsoil water.
Deep-well water.
Spring water.
River water.

Each of these sources will be separately considered.

CHAPTER II.

RAIN AND RAIN WATER.

When water is boiled in a suitable vessel and the steam passed through some form of cooling apparatus the vapour is condensed, and water flows from the open end of the cooled tube. This is the process of distillation, and water so obtained is called "distilled water." As the water approaches the boiling point the less soluble gases are evolved, but the more soluble ammonia (if present) distils over with and is contained in the first portions of the distilled water. The saline constituents of the water, being non-volatile, remain behind in the vessel in which the water is being boiled. As stated in the last chapter, water slowly evaporates into the air at all temperatures, and at 10° C. (50° F.) 1 cubic yard of air can contain 150 grains of water, at 21° C. (70° F.) about twice this amount, and at 0° C. (32° F.) about half. If, therefore, 1 cubic yard of air saturated with moisture at 21° C. be cooled to 0°, it would deposit about 225 grains of water in the form of dew or rain. The ocean has been compared to a boiler, the sun to a furnace, and the atmosphere to a vast still. The cooler air of the higher atmosphere and of colder zones acts as the condenser, causing the precipitation of the distilled water as rain. About three-fourths of the earth's surface, or 145,000,000 of square miles, is covered with water, three-fifths of which is south of the equator. The surface of the water is heated by the direct rays of the sun, and evaporation is rapid, especially in tropical regions.

Somerville estimates that "186,240 cubic miles of water are annually raised from the surface of the globe in the form of vapour, chiefly from the inter-tropical seas. The evaporation over the surface of the ocean is so great that, were it not restored, it would depress its level about 5 feet annually." Ansted says that "about 7,000 ℔ weight of water are evaporated every minute, on an average, throughout the year from each square mile of ocean."* Besides this evaporation from the ocean, evaporation is constantly going on from the surface of the land, the amount varying with the season and climate, the nature of the soil, and the character of the vegetation. When discussing the amount of water obtainable from various watersheds, this question of evaporation will receive further consideration. According to Somerville "the vapour from the great reservoirs at the equator and the southern hemisphere is wafted by the south-east trade wind in the upper regions of the atmosphere till it comes to the calms of Cancer, where it sinks down and becomes a south and south-west surface wind, and then the condensation begins that feeds all the great rivers of the world." Moisture-laden air if cooled sufficiently will give up a portion of its water in the form of mist (cloud) or rain, the amount of water condensed varying with the degree of saturation of the air in the first instance, and the extent to which the temperature is reduced. This cooling is produced in three ways—(*a*) by the ascent into the higher regions of the atmosphere, the temperature falling about 3° C. for every thousand feet ascended, (*b*) by contact with cold surfaces, as of the sides of mountains, and (*c*) by admixture with colder air. The first cause is by far the most important, the last can only under comparatively rare circumstances be the cause of rain. The importance of the second is sometimes over-

* "All the coal which men could dig from the earth in many centuries would not give out enough heat to produce, by the evaporation of water, the earth's rain supply for a single year."—Symons' *Met. Mag.*, vol. v.

rated, since to it is often attributed the excessive rainfall in hilly districts and mountainous regions. The effect of the hills is principally to direct the air currents impinging upon them upwards, and therefore into colder regions. The lowest stratum of air only can be chilled by contact with the ground. As Eaton * points out, "if this contact with the cold ground were sufficient to cause rain, we should invariably have rain when in the winter months a warm and saturated south-west wind succeeded a frost, as long as the ground remained unthawed, instead of a thin surface fog, as usually obtains." In the British Islands the westerly are the chief rain-bearing winds. As the west coast is mountainous, such winds are directed upwards by contact with the hillsides; the cold produced by the expansion first condenses the vapour into cloud and finally into rain. Most of the rain is deposited on the western slopes; the clouds, having passed over the range of hills, tend to sink, become warmer, and disappear. Thus the westerly winds are comparatively dry by the time the opposite coast is reached, and as easterly winds blowing over the European Continent usually contain but little moisture, the rainfall on the east coast is far less than that upon the west. In England, east of a line extending from Shields to Reading and north of the Thames, the average rainfall per annum is only about 23 inches; along the south coast it is about 35 inches; whilst in the mountainous districts of Cumberland, Westmoreland, Wales, and Devonshire, the average exceeds 75 inches. Up to about 2,000 feet the amount of rainfall increases with the elevation; above this level, the clouds having already deposited most of the moisture they originally contained, the amount decreases, or at least no longer increases. Where the hills do not reach 2,000 feet, and where they are cut through by valleys, more rain is deposited on the lee side of the

* *Proc. Brit. Met. Soc.*, 1861.

hills and over the country opened out by the valleys. The following gaugings by Mr. Bateman, taken along the line of the Rochdale Canal across the Pennine Chain * " show to a marked degree the abstraction of moisture caused by the intervention of a range of hills":—

ANNUAL RAINFALL.

At Rochdale	34·25 inches	At foot of western slope.
White Holmes, Blackstone edge	52·55 ,,	1,200 feet above sea-level.
Toll Bar ,,	53·16 ,,	1,000 feet above sea-level.
Black House ,,	51·80 ,,	1,000 feet above sea-level.
Sowerby Bridge . . . at foot of eastern side of the hills.	29·85 ,,	300 feet above sea-level.

Over some five-and-a-half millions of square miles of the land surface of the globe rain seldom or never falls—(the deserts of Sahara, Gobi, Kalahari, the interior of Australia, etc.). Near the equator the rainfall is almost perpetual. At Cherraponjee, in the Khasia Hills, in Assam, the average rainfall is over 400 inches. Probably the wettest district in England is the Stye Pass, in the Cumberland Hills, where about 200 inches fall annually, the average over the whole of England being about 30 inches. Speaking generally, the rainfall varies with the latitude, altitude, distance from the sea, direction of the prevailing winds, extent of forests, and position with reference to mountain ranges.

The rainfall also varies greatly at certain seasons. Over nearly the entire sub-tropical region winter is the rainy season. According to Scott † the exceptions are "the eastern coast of the great continents, as China and the eastern states of the Union, which enjoy a sort of monsoon rain in the height of the summer. Natal in Africa and the Argentine Republic come under the same category.

* De Rance, *The Water Supply of England and Wales.*

† *Elementary Meteorology.*

All these countries receive abundant rains at the period most favourable for the growth of crops. . . . The countries with winter rains and summer droughts must have recourse to irrigation to water their fields." In other regions farther north, rain falls at all periods of the year, as in the British Isles. On the west coast most rain falls in January, but on the opposite coast September, October and November are the wettest months. The mean monthly rainfall at Kew, Greenwich, and in Massachusetts for various periods is given in the subjoined table:—

	Kew.	Kew.	Greenwich.	Massachusetts.*
	1813-72.	1865-80.	1881-90.	
January	1·9	2·2	1·3	3·7
February	1·5	1·7	1·3	3·6
March	1·5	1·3	1·3	3·9
April	1·7	1·85	1·3	3·3
May	2·1	1·6	1·6	3·3
June	2·0	2·1	1·6	3·3
July	2·3	2·4	2·2	3·8
August	2·3	2·2	1·6	4·1
September	2·35	2·5	1·7	3·0
October	2·7	2·5	1·9	3·7
November	2·3	1·9	2·0	3·9
December	1·9	2·2	1·4	3·5

The variation in the rainfall in any given district in different years and in different parts of the year has an important bearing upon the question of water storage, and will be considered in the section treating of that subject.

A precise knowledge of the amount of rainfall is absolutely necessary where the total amount of water falling upon a given area has to be ascertained, and this knowledge can only be obtained by careful collection and registration. Such records also, if properly kept, are of the greatest service in enabling approximate estimates to be made of

* Average deduced from long-continued observations in various parts of the State. Report on Water Supplies, 1889-90.

the amount of water which can be collected, and for comparing the rainfall over different areas. It is very desirable, therefore, that some uniform plan of collection and registration should be adopted. The Royal Meteorological Society gives to its observers the following instructions (*Hints to Meteorological Observers, with Instructions for Taking Observations*):—

"*Rain-gauge.*—The rain-gauge should be made of copper,

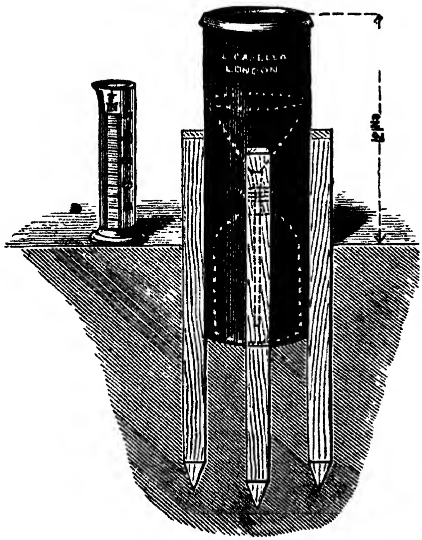

FIG. 1.—Snowdon Rain-guage.

and have a circular funnel of either 5 or 8 inches diameter, with a can or bottle inside to collect the water. It is very desirable that it should be of the Snowdon pattern—that is, with a 6-inch cylinder and a sharp brass rim (Fig. 1).

"It should be set in an open situation, away from trees, walls, and buildings—at the very least as many feet from their base as they are in height—and it should be so

firmly fixed that it cannot be blown over; the top of the rim should be one foot above the ground, and must be kept quite level.

"The measurement of the rainfall is effected by pouring out the contents of the water of the bottle or can into the glass measure, which must be placed quite vertical, and reading off the division to which the water rises; the reading is to be taken midway between the two apparent surfaces of the water. The glass measure is usually graduated to represent tenths and hundredths of an inch, and holds 0.50 inch of rainfall. Each division represents the one-hundredth of an inch, the longer divisions five-hundredths, and the long divisions, having figures attached, tenths of an inch. If there be more than half an inch of rain, two or more measurements must be made, and the amounts added together. The complete amount should always be written down before the water is thrown away. The gauge must be daily examined at 9 A.M., and the rainfall, if any, entered to the previous day; if none be found, a line or dash should be inserted in the register. It is desirable that very heavy rains should be measured immediately after their occurrence, entering the particulars in the remarks, but taking care that the amount is included in the next ordinary registration.

"*Snow.*—When snow falls, that which is collected in the funnel is to be melted and measured as rain. This may quickly be done by adding to the snow a measured quantity of warm water, and afterwards deducting the quantity from the total measurement. If the snow has drifted, or if the funnel cannot hold all that has fallen, a section of the snow should be obtained in several places where it has not drifted by inverting the funnel, turning it round, lifting and melting what is enclosed. The section should, if possible, be taken from the surface of a flat stone."

In mountainous districts, and for waterworks purposes, in which it is only necessary to make weekly or monthly

observations, a special form of rain-gauge must be used.* Mr. Symons' pattern is admirably adapted for this purpose (Fig. 2). The cylinder in which the water is collected will

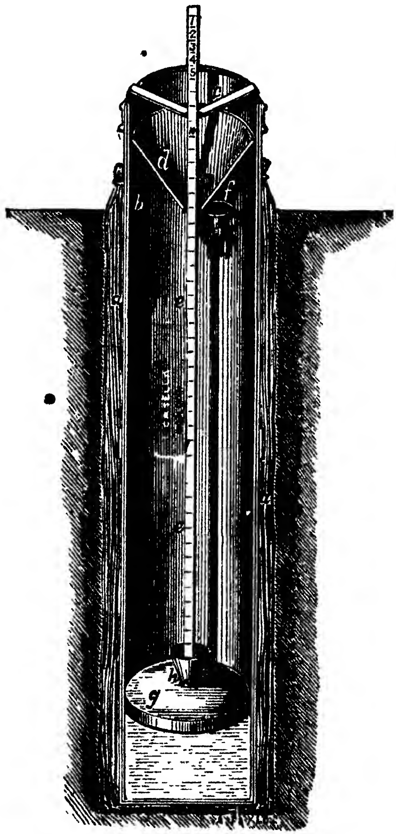

FIG. 2.—Symons' Mountain Rain-gauge.

contain 48 inches of rain, and by aid of a graduated rod and float, readings may be taken to one-tenth of an inch. The rod is detached and only introduced when an

* MM. Richard Frères of Paris make a self-registering rain-gauge.

observation is being made. In districts where the annual rainfall does not exceed 40 inches, the collecting cylinder may be of smaller capacity. If the area of the mouth of the funnel be twice that of the cylinder, the float will rise 2 inches for each inch of rain, and the accuracy of the readings is increased.

One inch of rainfall corresponds to nearly $4\frac{3}{4}$ gallons per square yard, or 22,620 gallons per acre. If 1 inch of rain fell upon some impervious surface, such as a roof, covering say 10 square yards of ground, the amount of water which could be collected, providing none were lost by evaporation or from any other cause, would be $46\frac{3}{4}$ gallons. To obtain anything approaching this amount, however, the rain would have to be heavy and continuous. If it fell in a series of slight showers spread over any considerable interval, and especially in hot weather, only a very small proportion indeed would be collected—nearly all would be lost by evaporation. When the rain falls upon more or less pervious soil covered with vegetation, it is only the heavy rains or long-continued showery weather which yields sufficient water to percolate into the subsoil to feed the springs and raise the level of the subsoil water (*vide* Chapter IV.). The total rainfall and the rainfall available for water supplies are therefore not identical terms.

Rain water collected from a clean, impervious surface in the open country is the purest of natural waters. In passing downwards through the air, however, it not only takes up a proportion of the gaseous constituents, but also washes from the air all floating impurities, whatever their nature. The rain which first falls always contains the largest proportion of these impurities. In the neighbourhood of towns the rain contains soot, sulphuric acid, and other matters derived from the combustion of coal, together with ammoniacal salts, nitrates, and albuminous matters derived from decomposing animal and vegetable substances, and the exhalations from the bodies of men and

animals. Minute traces of these substances, together with common salt (derived from the sea) and various micro-organisms, are found in all rain waters.

One gallon of rain contains on an average 8 cubic inches of gases, of which about one-third is oxygen and two-thirds nitrogen. The carbonic acid amounts only to about two per cent. of the mixed gases.

Dr. Angus Smith, in his work on *Air and Rain*, states that rain from the sea contains chiefly common salt; that the sulphates increase inland before large towns are reached, and seem to be the products of decomposition, the sulphuretted hydrogen from organic compounds being oxidised in the atmosphere; that the sulphates rise very high in large towns because of the amount of sulphur in the coal used, as well as to decomposition; that when the sulphuric acid increases more rapidly than the ammonia, the rain becomes acid; that free acids are not found with certainty where combustion or manufactures are not the cause; and that ammoniacal salts increase in the rain as towns increase: they come partly from coal and partly from decomposed organic substances. The observations of Dr. Miguel at Montsouris, Paris, on the micro-organisms found in rain, prove that bacteria, pollen, spores of fungi, protococci, etc., constantly occur, and are especially numerous in the warmer months; and in the first showers after a long spell of dry weather over 100,000 such organisms may occur in a single pint of rain water.

The foregoing remarks refer only to water collected directly in clean vessels. If the rain has fallen upon a roof it may become seriously contaminated by the excrement of birds, decaying vegetable matter, soot, and dust; in fact some of the filthiest waters used for domestic purposes which I have examined have come from rain-water tanks. The solid organic matters are washed from the roof or other collecting surfaces into the tanks; these undergo further putrefactive change, the products formed entering into

solution and accentuating the pollution. When properly collected, rain water can be stored and utilised for all domestic purposes. Since it never contains more than a trace of lime salts in solution, it is exceedingly soft and well adapted for washing. Its taste is mawkish and objectionable, but this can be remedied by filtration; in fact it can be rendered quite palatable. Rain water, especially in certain districts where manufacturing towns abound, is frequently distinctly acid, and then acts freely on various metals. It is not safe, therefore, to store it in lead, zinc, iron, or galvanised iron tanks. Slate tanks may be used, but if the joints are made with white or red lead, the angles where the lead is exposed should be filled in with cement. This not only prevents the lead being acted upon, but renders the jointing more secure and facilitates cleansing. Earthenware can be used for small cisterns. Large storage tanks may be built of brick, and, if underground, should be well puddled outside with clay. The bricks should be set with hydraulic lime mortar and the inside of the tank lined with Portland cement. The object of these precautions is not only to prevent the rain water wasting by leakage, but also to prevent ground water gaining access. Access of surface water must also be guarded against by roofing over in a similar manner. By proper collection and storage of the rainfall it is often possible to obtain a fairly abundant supply of good water for a farm, dwelling-house, or even a group of houses. To effect this, three conditions are necessary:—(1) The tank must be of sufficient size to store all the available rainfall, and must be properly constructed. (2) The first portion of every shower which washes the roof or other collecting surface, and is therefore always filthy, must not be allowed to enter the storage tank. (3) There must be some efficient system of filtration. The area covered by the average country cottage may be taken at 35 square yards, and the available rainfall collected from a roof cannot safely be

estimated at more than half the total rainfall. Much is lost by evaporation; many slight showers do not yield enough water to reach the tank, and in very heavy showers much is often lost by the water running over the eaves troughing, or over the ends of the cottage where there is no spouting. Assuming the rainfall to be the average, from 15 to 18 inches could be collected. This would yield for the year about 3,200 gallons, or 9 gallons per day. It is evident that this would not be sufficient to meet all requirements; but even in the worst districts there are ponds or brooks from which water could be obtained for slopping purposes. With a larger roof area, of course a larger amount of rain water would be available; but as few cottages cover an area of 40 square yards, about 9 gallons would be the maximum supply. In the eastern counties, where the rainfall is only from 20 to 25 inches, even this amount cannot be obtained, but in districts where the rainfall exceeds the average more could be collected. The amount of water required on farms is necessarily larger than in cottages, but even the increased collecting area from the roof of the house and outbuildings would not give a relatively more abundant supply.

As the water is in constant use, the storage tank need not, of course, be so large as to hold at one time the whole of the amount collected during the year. It will be sufficient if it is one-fourth or one-third this size—that is, if it hold a rainfall of at least 4 inches. To do this, the tank must have a capacity of 3 cubic feet for each square yard covered by the roof (not of actual roof area). For a country cottage, under the conditions assumed above, the storage space must be 105 cubic feet. This would be approximately furnished by a tank 6 feet square and 3 feet deep, or by a circular tank 4 feet 8 inches in diameter and 6 feet deep, or 5 feet in diameter and 5½ feet deep. For larger roof areas the size of the storage cistern can easily be calculated.

To separate the first portion of the rain water, Roberts's Rain-Water Separator may be used. "It rejects the dirty and stores the clean water. It is made of zinc, upon an iron frame, and the centre part or canter is balanced upon a pivot. It is self-acting, and directs into a waste pipe the first portion of the rainfall, which washes off and brings down from the roofs soot and other impurities. After rain has fallen a certain time the separator cants and turns the pure water into the storage tank." The vertical form is used where a single stack pipe carries the water from the roof to the tank. One length of the stack pipe is removed, and the separator is inserted and fastened to the side of the house. When a building is provided with several stack pipes connected by an underground pipe leading to the tank, the horizontal form should be used. Various sizes of the apparatus are made, costing from £3 to £6, and it can be fixed by any intelligent workman.*

Fig. 3 shows the vertical separator in the position that it retains when running foul water into the waste pipe during the first part of a shower, while the roof is yet dirty.

Fig. 4 represents it when it has canted and has begun to pass the pure water into the storage tank.

One cannot but regret to see in rural districts, where water famines occur almost every summer, so little effort made to utilise the rainfall. Any kind of old cask or tank is considered good enough in which to store the rain, and little or no care is taken to so securely cover the receptacle as to prevent impurities getting in. Separators are not yet generally used, and therefore the water which is col-

* The author some time ago ordered one of the vertical separators to be affixed to a farmhouse. Shortly afterwards he received a complaint that very little water was collected, and that it was filthier than before. Upon examination he found that the workman had so fixed the separator that the washings of the roof ran into the tank, whilst the pure water ran into the drain.

lected is more or less filthy from the first. Occasionally there is some pretence to filtration, the stack pipe discharging over a bed of sand and gravel with or without

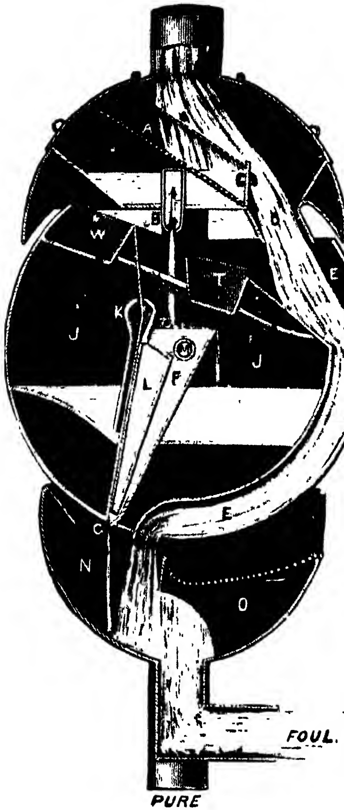

Fig. 3.

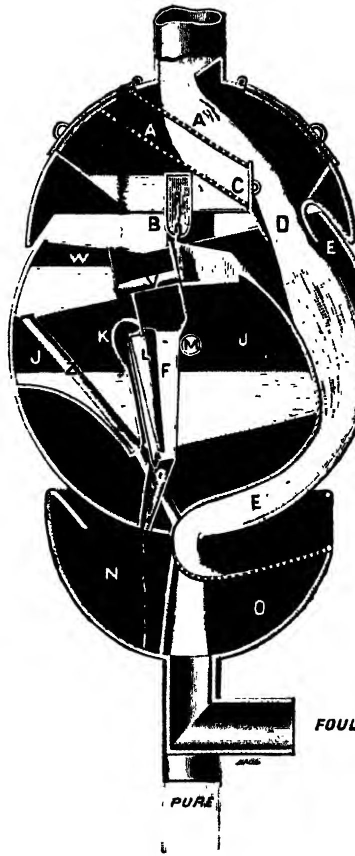

Fig. 4.

charcoal. For filtration to be of any service the material must be so fine as to allow the water to pass through but slowly. As a rule, the more rapid the filtration the less

the purification (*vide* Chapter XIII.); and if a small filter is to transmit a heavy rainfall it is evident that it must be too coarse to be more than a strainer. If finer material were placed in such a filter chamber, a considerable portion of every heavy rainfall would run to waste. Where a separator is used comparatively little sediment is formed in the tanks, and the water is sufficiently clean and bright for every purpose save that of drinking. For table purposes it should be passed through some good form of filter, or the separated rain water may be collected as it falls in the receptacle to a filter, and allowed to slowly percolate through the filtering media into a collecting tank, from which it can be drawn in any convenient manner. The filter should be fitted with a loose cover, so that whenever necessary the top layer of sand can be removed and replaced by fresh, or the filter be otherwise cleaned. The receptacle receiving the water from the "separator" should be sufficiently large to hold ½ an inch of rainfall upon the whole collecting area.

If, instead of merely utilising the roofs of buildings for collecting rain, the surface of a portion of ground be rendered impervious, any quantity of water may be obtained. In many cases a plot of ground could be selected at such an elevation as to supply the mansion, farm, or cottages with water by gravitation, so saving all the expense of pumps and pumping. Mr. Eardley Bailey Denton, M.I.C.E., writing in *The Field*, 18th June, 1887, says, "1 inch of rain falling on the surface of an acre is equivalent to 22,622 gallons; and supposing that half an acre of land be set apart and rendered impervious for the collection of rain falling on it during the six winter months, the amount collected where the rainfall is least, as in the east of England, during that period would be about 170,000 gallons (assuming the winter rainfall to be 15 inches), or enough to satisfy the wants of nearly 100 persons for a period of three months (an exceptionally long drought) at 20 gallons a

head daily, an ample quantity for all individual and household purposes. Tanks can be built at a cost varying from £3 to £5 per 1,000 gallons, and on the chalk formation, where scarcity is soonest felt, at even less cost. In most cases a collecting area can be selected free from contamination. The area upon which the water would be collected need merely have a concrete floor with cement surface, railed off to prevent stock running over it, and the storage tank may be constructed underneath." The above estimate of the amount of water which could be collected does not appear to be excessive, and many mansions are now being satisfactorily supplied in this manner. To purify the water a simple filter at the end of the suction pipe in the underground tank, supplemented also by a filter along the course of the house supply, is recommended. This second filter is fixed below the house cistern in an accessible position, so that the contents can be easily cleaned. Unfortunately this plan is too expensive for groups of cottages—that is to say, the cost per house would exceed that which a Sanitary Authority can compel the owner to expend in obtaining a supply (about £8 per cottage). The roof area of most mansions is so much greater per inhabitant than the roof area of cottages, that a much more abundant supply is procurable. Probably 20 square yards per person is an average in a mansion. This would yield about 1,500 gallons per year, or 4 gallons per head per day. The house cistern should be capable of holding about a week's supply, and be filled up every day. The need for a cistern so large is due to the fact that the demand for water is very unequal, three or four times as much being used some days as others.

The rainfall is the source of all our water supplies; but unless caught upon artificially-prepared surfaces, such as roofs and specially prepared cemented surfaces, it is not called rain water. That which falls upon rocks, either bare or with little vegetation, when collected is called

"upland surface water"; that which falls upon and is collected from moors is "moorland water"; that which runs off the surface of pasture lands, "surface water from cultivated ground"; that which percolates through the surface soil into a pervious subsoil is "subsoil water"; whilst that which travels through the subsoil under impervious strata, so that it can only be reached by boring through such strata, is "subterranean or deep-well water." Where an impervious stratum comes to the surface and throws out the subsoil water from the pervious stratum above, a land spring is formed, whilst subterranean water thrown to the surface in any way forms an "ascending or deep spring." The waters in streams may be derived from any one or more of these sources; river water is usually a mixture of all, together with sewage and other impurities received from the towns and villages along its course. Speaking generally, deep springs yield the purest waters, and rivers the most impure; they may be arranged in order of purity as follows:—

Deep-spring water.
Subterranean or deep-well water.
Upland surface water.
Moorland water.
Subsoil water (if distant from any aggregation of houses).
Land springs.
Surface water from cultivated ground.
River water.
Subsoil water under villages and towns.

The R.P.C. give a lengthy Table of Analyses of carefully-collected rain water (78 samples), and of rain water as ordinarily collected and stored in tanks (8 samples). The following are the means of their results.

	Fresh Rain Water.	Tank Water.		
Total Solids .	2·76	16·8	grs.	per gallon.
Nitric Nitrogen	·004	·78	,,	,,
Chlorine .	·43	1·6	,,	,,
Hardness .	·42	7·9	,,	,,
Free Ammonia	·50	1·15	pts.	per million.

CHAPTER III.

SURFACE WATER.

IGNEOUS, Metamorphic, Cambrian, Silurian, and Devonian rocks resemble each other in being practically impervious, and very slightly acted upon by water; and the districts where such rocks are exposed are usually wild and mountainous, and in Great Britain at least have a rainfall much above the average. Rain falling upon such surfaces rapidly runs off, forming rivulets and streams, pools and lakes, the water from which differs but little from that of the rain from which it is derived. Certain limestones of the Silurian and Devonian systems, however, though very compact and hard, yield an appreciable trace of carbonate of lime to the water, causing it to have a hardness of from 6 to 10 or more degrees. The hardest rocks undergo a process of weathering, by the exposure of their surfaces to the action of the air and water. By the alternate freezing and thawing of water in the minute interstices, the superficial layers become disintegrated and yield a little soluble matter to the rain falling thereon. If the surface be very steep, the débris is washed away as formed; if not, it gradually accumulates, until there is sufficient to enable lichens and mosses to flourish. The decay of these plants furnishes mould or humus, upon which larger and more highly-organised plants may grow, and these by their death and decay furnish the beds of peat so common in certain districts. The rain falling upon such plant-covered surfaces is in part retained, some being returned to the atmosphere by evaporation from the surface of the soil, and from the

fronds and leaves of the plants covering it, the remainder slowly finding its way to lower levels, and ultimately into the streams and pools. Only during heavy rains will any quantity run directly off the surface. From the bare rocks, since the rain immediately flows away, comparatively little is lost by evaporation or absorption; rivulets and streams are quickly formed and almost as quickly disappear. Where the rocks are covered with vegetation the streams are more permanent, though fluctuating greatly. Much of the water, being retained for a time in the spongy mass of vegetable débris clothing the rock, is enabled to take up a certain amount of organic matter, sufficient frequently to impart a brownish colour and a peculiar bitter "peaty" flavour. These impurities are solely of vegetable origin, and unless excessive in quantity appear to have no injurious effect whatever upon the health.

The igneous rocks of Devon and Cornwall yield a water containing very little inorganic matter; but as peat is abundant in these districts, the organic matter derived therefrom may be considerable. Containing little or no carbonate of lime, they usually act freely upon lead (*vide* Tables of Analyses).

The Metamorphic, Cambrian, Silurian, and Devonian rocks, exposed in Wales and neighbouring counties, Westmoreland, Cumberland, Devon, and Cornwall, yield water very similar from a hygienic point of view to that from the igneous rocks. The metamorphic rocks (quartz, mica, schist, gneiss, granite, and crystalline limestone) may be said to be absolutely impervious, as may also the slates of the other series. The sandstones, however, are more or less porous, and absorb some portion of the rainfall. The calcareous rocks of the Silurian and Devonian systems are exceedingly compact, and the water from their surface is but little harder than that from the non-calcareous rocks.

The non-calcareous carboniferous rocks (Yoredale rocks, millstone grits and coal measures) occur in South Wales, Derbyshire, Yorkshire, Lancashire, and North Staffordshire, and are but slightly pervious. A considerable proportion of the rainfall on the slopes of the hills finds its way into the rivulets and streams, some of which are utilised for feeding reservoirs for supplying many of our manufacturing towns with water Certain of these waters are exceedingly soft, the average hardness being only 6°. They are therefore admirably adapted for use in steam boilers and for most manufacturing purposes. They are frequently peaty and turbid, but when carefully filtered usually form satisfactory domestic supplies. In certain districts the water is frequently acid, and then acts powerfully on lead. It is water from these sources which has produced the extensive prevalence of lead-poisoning in the Lancashire and Yorkshire towns.

The calcareous carboniferous rocks (carboniferous or mountain limestone and limestone shales) of Northumberland, North Yorkshire, Lancashire, and Mid-Derbyshire yield a water of a moderate degree of hardness, not so well adapted for many manufacturing purposes, but not too hard for domestic use, and free from any solvent action upon lead. The beds of limestone and sandstone in the coal measures are more freely acted upon by water, and that derived from the surface may be excessively hard, even exceeding 50°. 16° is given as the average. When the hardness is excessive the water is, of course, unsuitable for domestic use and for most manufacturing purposes.

The secondary rocks "stretch across England from the mouth of the Tees to the mouth of the Exe, with a branch running to the mouth of the Mersey." The lias, new red sandstone, conglomerate sandstone, and magnesian limestone formations yield from their

therein, but on account of their liability to pollution by cattle, by manure on the ground within their drainage area, etc. Being shallow, the whole mass of water may be frozen during a severe and continued frost, and any contained fish will perish; afterwards when the ice melts these will decompose and foul the water. Several instances of this kind have come under my notice in districts where the inhabitants depend upon ponds for their supply of water.

Suspended matters in surface waters may be removed by continued storage in large reservoirs or lakes, when time is given for the whole to subside, or by filtration through sand, which, however, is troublesome and somewhat expensive. The Massachusetts Commissioners point out "that when water is taken from the ground near streams and lakes it is often to a large extent surface water so thoroughly filtered that it cannot be distinguished from the natural ground water. This method of purification by natural filtration is an excellent one to adopt where there is a sufficient area of porous ground adjoining the surface water source."

The advantages of converting lakes into reservoirs for storing water, over the construction of artificial reservoirs, are so great that several towns have already adopted this plan. Glasgow is supplied with water from Loch Katrine; Liverpool, and several other towns, from Lake Vyrnwy in Wales; and Manchester from Thirlmere in Cumberland. As an example of a smaller town Aberystwith in North Wales may be quoted; it derives its supply of water from that portion of the rainfall on Plynlimmon which runs into the Llyn Llygad Rheidol Lake. The following account is taken in part from evidence given at an inquiry held by the Local Government Board, and contains many points of interest. The inquiry was held to sanction a loan of £16,000 to carry out the work. At the present time the town has a resident population of about 15,000, and in summer a considerable number of visitors reside

there. The scheme was completed in 1883, and the town has now an abundant supply of water of unexceptionable purity.

The source of supply is the Llyn Llygad Rheidol Lake, situated on Mount Plynlimmon, 16½ miles from Aberystwith, and about 1,650 feet above the sea. The wild nature of the country renders the possibility of pollution remote. The area of the lake is 11½ acres, its greatest depth 60 feet, and the available storage capacity, supposing the bank is raised, as proposed, 1 foot, and only 15 feet of water is drawn off, is nearly 40,000,000 gallons. This is equivalent to eighty days' supply for a population of 25,000 at 20 gallons per head (that is, for about twice the present population (1892), summer visitors included). This would be if no rain were to fall on the mountain for that length of time a supposition hardly ever likely to be realised. Plynlimmon rises about 2,500 feet above the sea, and is the highest peak in this part of Wales The warm winds from the south-west and west, coming laden with moisture, impinge on the mountain, and their temperature being suddenly reduced, copious falls of dew and rain take place. The lake is actually fed with rain that falls on the very summit of Plynlimmon, and it would only be in a most extraordinary season of drought that no rain would fall for more than 2½ months. The area draining into the lake is 133 acres. The actual rainfall is unknown, but the late Mr. Symons (the first authority on the subject) put it at over 75 inches At Nantiago Lead Mine, 800 or more feet below Plynlimmon, it was 92 inches in 1878, so that it may be 120 inches or even more at the summit of the mountain. The very moderate rainfall of 60 inches only is assumed. Very little would be lost by evaporation, the slopes of the mountain being so great that the water runs off most rapidly; and very little would be lost by percolation, as the mountain consists of Bala rock, the upper member of the lower Silurian beds, a hard and more or less imper-

meable formation. If, then, 60 inches only be taken as the available rainfall over 133 acres, the quantity flowing into the lake would be over 180,000,000 gallons, very nearly a year's supply at 500,000 gallons daily. If the available rainfall be 100 inches per annum (as indicated by gaugings of the outflow from the lake), the supply would be 300,000,000 gallons yearly. The water is carried from the lake to Aberystwith in an iron main 8 inches in diameter. Such a main, with the minimum gradient obtainable for it, will deliver more than half a million gallons daily. The water, before being distributed in the town, is discharged into a service reservoir, two-thirds of a mile from the town and 130 feet above the highest building in the place. The general pressure throughout the town is equal to a head of 200 feet. The capacity of the reservoir is 1,000,000 gallons. From the service reservoir the water is distributed to the town by a 10-inch main. The following is an abstract of the estimate:—

Cast-iron pipes, 34,117 cwts., at 5s. per cwt.	£8,529	5	0
10-inch main from service reservoir, 2,338 cwts.	584	10	0
Excavating trenches for pipes, and refilling 28,804 lineal yards at prices varying from 2s. in rock to 6d. in soft soil per yard	1,514	8	7
Laying pipes and jointing them	1,214	0	8
Extra for junctions and special pipes	110	0	0
Carriage of pipes	1,055	14	0
Sluice valves, flushing valves, air cocks, etc.	188	9	0
Posts to indicate line of main	25	0	0
Pressure-reducing tanks or break valves, and fixing ditto	217	10	0
Works at the lake for drawing off the water	185	0	0
Service reservoir, with valves, pipes, etc., complete	2,019	11	6
Contingencies, law charges, and engineering at 7½ per cent.	1,173	4	6
Total	£16,816	13	3

The works were duly executed, but the estimate was exceeded by about £1,000, a detour with the water main

having to be made on account of the peaty nature of the ground. It will be noted that no land had to be purchased, and that no compensation water had to be provided, both important matters for consideration when a public water supply is being provided.

At the Congress of the British Institute of Public Health held in 1893, in Edinburgh, the engineer to the City Waterworks gave a description of the Loch Katrine Waterworks supplying Glasgow. The paper contains much that is interesting, and to it I am indebted for many of the following particulars. When the scheme was first propounded, Glasgow had a population of 350,000, and it was estimated that it would increase to 760,000 in 1900, and that the consumption of water would then be 30,000,000 gallons per day. The works were estimated to bring 50,000,000 gallons per day. However, both these estimates have proved erroneous, since the population now (1898) being supplied with water is 1,000,000, and the consumption of water has risen from 40 to 54 gallons per head, so that 54,000,000 gallons are now used every day. The increased quantity used is attributed to several factors: the introduction of baths into the houses of the well-to-do working classes; the compulsory fitting up of water closets in even the smallest class of houses; the increase of public urinals, watering-troughs for cattle, drinking and ornamental fountains; the introduction of several large public swimming baths. Loch Katrine is 368 feet above the sea. The area of the loch is $4\frac{3}{4}$ square miles, and its drainage area $36\frac{1}{4}$ square miles. By means of a small masonry dam at the outlet the loch has been raised four feet above the old summer level, and can be drawn down 3 feet below that level. In this range of 7 feet there is comprised a storage of 5,623,000,000 gallons, or 102 days' supply. The surrounding hills rise to a height of from 2,300 feet to nearly 3,000 feet; and as a result of this and the proximity of the

district to the west coast, which first receives the moist south-west winds of the Atlantic, the rainfall is very large. At Glengyle, at the top of the loch, the fall is frequently over 100 inches per annum, and the driest year during the last 40 years (1880) yielded 69 inches. The loch is so deep that the water never freezes except in shallow and sheltered bays. Temperature observations made in 1885 and 1886 show that the water reached its lowest temperature of 38.7° F. near the bottom, in March, whilst at the top it was 38.1°, and that during the rest of the year the surface water was warmer than the deep water. Geologically the district round the lake consists of metamorphosed mica schist of the lower Silurian system, yielding very little mineral matter to the rain falling upon it. The district is practically uninhabited, and by a payment of £17,600 to the proprietors of the land they have surrendered all rights of feuing and of erecting houses, or of allowing additional steamers or boats to ply on the lake. There is much peat on the hill tops, and in times of flood the streams are highly coloured, but the relatively large size of the loch and its great depth have an important influence in removing the peaty stain. Analysis shows that it is a very pure water, exceedingly soft (hardness under 1°). Notwithstanding this no case of lead-poisoning through using it has ever been reported. A service reservoir 8 miles from Glasgow holds eleven days' supply. The aqueduct was expected to pass 50,000,000 of gallons per day, but the effect of the roughness of the channel in retarding the flow (friction) was much more than had been anticipated, and the flow is only 42,000,000. The total cost of the works, including $11\frac{3}{4}$ miles of tunnelling, $10\frac{1}{4}$ miles open cutting and bridges, $13\frac{3}{4}$ miles cast-iron syphon pipes across valleys, and piping within distribution area, has been close upon £1,500,000. This also includes works carried out at other lochs to provide 40,000,000 gallons of compensation water. Duplication of these works is now being carried out which, it is

estimated, will allow of 100,000,000 gallons of water per day being drawn from the loch for the supply of the city, at an additional cost of £1,300,000. The domestic water-rate, which in 1856 was 1s. 2d. per £1 of rental, has been reduced to 5d. per £1 (1900).

The Derwent Water Act (1899) marks an epoch in the history of water supplies, dealing exhaustively with the whole of the water available in the Derwent watershed, and allocating it amongst all the districts having claims thereto. It provides for a Water Board, consisting of representatives elected by the Derbyshire County Council and by the Corporations of Derby, Leicester, Sheffield and Nottingham. The works which this Board can carry out will be capable of affording a supply of 30,000,000 to 33,000,000 gallons per day, and the estimated expenditure of the Board on the proposed works is £5,500,000. The supply is allocated as follows:—

For the use of the districts within the County of Derby	5	million galls.	per	day.
Derby Corporation	7	,,	,,	,,
Leicester ,,	10	,,	,,	,,
Nottingham Corporation	4	,,	,,	,,
Sheffield ,,	7	,,	,,	,,

This scheme will afford a supply of 6,000,000 gallons of water per day per million of money expended. A scheme for supplying Birmingham from the Elan and Claerwen watersheds, now approaching completion, is estimated to give 10,000,000 gallons per day for the same sum, but the collectable rainfall in the Welsh valleys is 40 per cent. more than in the Derwent Valley.

TABLE I.

Analysis of Public Water Supplies Derived from Uplands and Moorlands.

No.	Analyst.	Town Supplied.	Geological Formation.	Physical Character	Grains per Gallon. Total Solids.	Nitric Nitrogen.	Chlorine.	Temporary Hardness.	Total Hardness.	Action on Lead.	Parts per Million. Free Ammonia.	Albuminoid Ammonia.	Nitrites.	Oxygen used in 4 hours.
1.	R. H. Harland, F.I.C.	Plymouth	Granite and Trap	Peaty Brown	1·96	·01	·8	·0	1·5	..	·007	·02	...	1·24
2.	J. C. Thresh, D.Sc.	Aberystwith	Lower Silurian	Yellow brown	2·0	·0	·5	·5	·5	Slight	·00	·05	·0	1·24
3.	T. P. Blunt, F.I.C.	Towyn	Cambrian and Silurian	Do	6·0	06	1·9	1·5	2·5	...	·00	·03	·0	·05
4.	Dr. Mills, F R.S.	Glasgow	Lower Silurian	Clear	2·0	·004	·4	..	1·0	..	·0	...	...	..
5.	F. Rimmington, F.I.C.	Dewsbury and Heckmondwike	Millstone grit	Yellow and acid reaction	4·3	·10	·5	1·6	2 9	Slight	·0	·24	...	..
6.	Dr. Thresh, F.I.C.	Leeds	Do.	Faintly coloured	6·0	·04	·8	·7	4·0	..	·02	·04	...	·55
7.	Dr. Thresh, F.I.C.	Buxton	Do.	Nearly colourless	3·0	·04	·52	...	2·8	...	·005	·055	·0	·46
8.	J. C. Brown, D.Sc.	Preston	Do.	Slightly peaty	5·5	·02	·8	...	2·5	...	·11	·21	...	..
9.	Dr. Sargent	Carnforth	Do.	Brownish	12·0	05	1·0	·0	7·0	...	·05	·03	...	...
10.	Dr. Thresh	Manchester	Do.	Do.	6 0	·10	·7	·0	2·5	Slight	00	·04	·0	·64

11.	Do.	Batley	Do.	Do.	5·0	045	3·0	·0	3·	Energetic	·00	·06	·0	1·67
12.	Do.	Staleybridge	Do.	Do.	6·0	·08	3·5	·0	3·5	Do.	·00	·04	·0	·93
13.	Do.	Halifax	Do.	Do.	5·5	04	·7	1·0	2·5	Slight	·04	·06	Trace	1·38
14.	Dr. Young	Okehampton	Metamorphic Rocks	Peaty and often acid	5·0	·1	1·0	·0	3·0	Acts when acid	·004	·086	·0	...
15.	Dr. C. Brown	Liverpool	Vyrnwy Lake, Silurian	Peaty	6·3	·0	1·0	..	3·0	...	·05	...	...	...
16.	Do.	Do.	Millstone grit	Do.	6·3	·014	·98	...	2·5	S. Acid	·04	...	...	...
17.	Dr. Symons	Merthyr Tydfil *	Old Red Sandstone	Do.	8·3	·04	·6	·9	...	None	·06	·07	Trace	2·31
18.	W. J. Orsman, F.C.S.	Wigan	Coal Measures	Greenish yellow	18·4	·07	1·1	3 0	9·	None	·03	·03	·0	1·00
19.	Wynter Blyth	Barnstaple †	New Red Sandstone	Yellowish	8·8	·02	1·5	2·8	4·6	...	·01	·24	...	1·86
20.	Dr. Thresh	Boston	Cultivated Calcareous	Do.	23·0	·15	1·3	16·0	17·	None	·01	·09	·0	1·20
21.	Do.	Stroud	Cultivated Calcareous and Fuller's earth.	Do.	26·0	·09	8	18·5	23·	...	·00	·10	·0	1·07
	Massachusetts State, Board of Health Report, 1890.	Average of 23 town supplies	Chlorine Normal	Nearly all with brownish tint	2·8	·004	Excess ·0	...	...	...	·01	·06	...	...
		Average of 25 towns	Chlorine within limit of error	Do.	2·7	·004	·014	..	...	...	·01	·17	...	...
		Average of 33 towns	Chlorine in excess	Do.	2·9	·007	·07	..	...	...	·02	·20	...	...
		Average of 6 towns.	With largest excess of Chlorine	Do.	5·7	016	·42	...	..	.	·10	·30	...	...

* Not a favourable sample. Of late years the total solids have gone up from 2·1 to 8·3 grains per gallon, probably owing to more extensive cultivation of gathering ground.

† Filters undergoing repair.

TABLE II.

ANALYSES OF UPLAND SURFACE WATERS, FROM REPORT OF RIVERS POLLUTION COMMISSIONERS, 1868.

In grains per gallon.

Geological Formation	Total Solids			Hardness.			Chlorine.		
	Lowest.	Highest.	Average.	Lowest.	Highest.	Average.	Lowest.	Highest.	Average.
1. Igneous Rocks	1·1	8·9	3·6	·6	4·1	1·5	·23	1·5	1·1
2. Metamorphic, Cambrian, Silurian, and Devonian	1·5	8·7	3·6	·3	4·8	1·8	·10	2·3	·6
3. Calcareous portion of Silurian and Devonian	8·6	10·1	9·6	5·2	6·7	6·0	·6	1·1	·8
4. Yoredale and Millstone grits, and non-calcareous portion of Coal Measures	3·2	10·5	6·1	·6	6·3	3.3	·45	1·1	·7
5. Calcareous portion of Coal Measures	7·1	54·1	16·0	4·3	17·5	8·6	·6	3·4	1·0
6. Mountain Limestone	8·7	16·4	11·9	6·9	10·2	8·9	·64	1·1	·9
7. Lias, New Red Sandstone, Conglomerate and Magnesian Limestone	7·8	18·4	13·2	4·2	17·4	9·9	·7	1·4	1·0
8. Oolite (one sample only)	..	..	12·2	...	...	8·7	...	...	1·5
9. Lower London Tertiaries and Bagshot Beds	4·1	9·2	5·9	1·3	3·9	2·7	·9	1·8	1·4
10. From Cultivated Land—									
(a) Non-calcareous	3·7	12·7	6·7	1·5	7·1	3·4	·5	2·0	1·0
(b) Calcareous	9·3	77·3	20·7	5·5	47·1	14·4	·4	8·8	1·6

CHAPTER IV.

SUBSOIL WATER.

THE subsoil or stratum immediately underlying the surface soil may be of a pervious or impervious character. If pervious a considerable portion of the rain falling upon the soil will pass down into it, if impervious only a relatively small portion will percolate, the larger portion running off

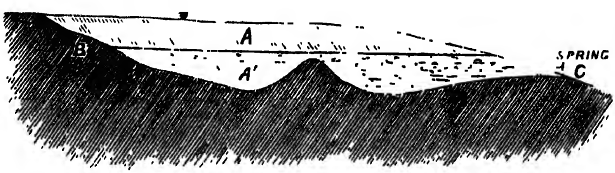

FIG. 5.—*A*, Pervious subsoil; *A'*, Portion saturated with water, *B*, Impervious stratum; *C*, spring.

as surface water. Where such an impervious rock occurs covered only with the spongy débris of vegetation, saturated with water, we have bogs, marshes, and swamps. The district will probably be malarial and the water of a dangerous character. Where a pervious subsoil of sand, gravel, chalk, limestone, sandstone, or other rock overlies an impervious rock such as clay, granite, hard limestone, etc., a portion of nearly every rainfall enters the subsoil, and being held up by the impervious layer below tends to accumulate. The water thus held in the interstices of the rocks lying immediately beneath the soil is "subsoil" or "ground" water. Where the pervious subsoil fills in a

hollow in the more impervious stratum, as in so-called pockets of gravel, the ground may become waterlogged—that is, completely saturated with water. If, however, at any one or more points the edge of the containing basin is depressed, water will overflow, forming a spring. Such overflow will only take place when the water in the porous rock has its surface level raised above that of the outlet. The portion below this will still remain stagnant. Where the porous subsoil rests upon a flat or sloping impervious substratum, the subsoil water will be constantly in motion, travelling towards the lowest point, where the impervious rock outcrops. There it will either issue as a spring, or

FIG. 6.—*A*, Pervious rock; *B*, Subsoil water; *C*, Spring; *D*, Stream; *E*, Clay or other impervious stratum.

act as the invisible feeder of a stream or lake. "The action of the soil in regard to water is in reality of a threefold nature: it may transmit water as wine is transmitted by a strainer; it may imbibe the moisture just as ink is soaked up by blotting-paper; and it may hold or be saturated by water, as a sponge immersed in water is saturated by liquid which flows from it when the sponge is lifted out. Thus we have to distinguish between the *permeability*, the *imbibition*, and the *saturation* of a rock. The amount of surface water which percolates through the soil depends upon the permeability; the amount retained as moisture of the soil depends upon the imbibition; the amount which can be held by the subsoil as ground water depends upon the saturation." * Clay exhibits in a high

* Miers and Crosskey, *The Soil in relation to Health.*

degree the property of imbibing water, but it is only very slightly permeable. Coarse gravels, on the other hand, are exceedingly permeable, but imbibe little, and have little storage capacity. The coarser the grain of any rock, the more freely will water traverse it, and the springs which it feeds will be more quickly affected by the rainfall. The water which penetrates the subsoil will either eventually flow out as springs (which will become dry unless the rain falls with sufficient frequency to keep up the supply of ground water), or if, from the contour of the impervious stratum below, the springs and outcrop are not at the lowest level of the water-bearing stratum, a certain amount of water will always be retained, forming, as it were, an underground reservoir. If, by pumping or otherwise, water be drawn from this reservoir, the outflow from the outcrop will be decreased by the amount so removed, and if sufficient be pumped the springs will cease to flow. The level of the water in the subsoil varies in different places and in the same place at different times. Where the porous stratum is of great thickness the water-level may be at a considerable depth, depending chiefly upon the elevation of the outcrop. The level also will vary with the rainfall, rising when the amount percolating is in excess of that flowing from the springs, or being artificially removed from wells, and falling when the percolation is less than the outflow. The rapidity with which the rise and fall follow the variations in the rainfall depends on the permeability of the subsoil and its depth. Prestwich states that on the chalk hills it takes from four to six months for the rainfall to reach the water-level if at a depth of 200 to 300 feet. On gravel and sand, with a water-level only a few feet from the surface, the rain would be absorbed and percolate much more rapidly, but probably would not affect the ground water level for many days. The varying level of the river into which the ground water is discharged will also affect its height, since when the river is in flood the ground water will be held back and rise. The fluctuation will be most

marked in wells near the river, and least in those at a distance. When the ground water enters the sea even the rise and fall of the tide may cause the height of the water to vary. The amount of water which can be retained in a rock varies considerably. Chalk and sand can hold about one-third their bulk of water; oolite one-fifth; magnesian limestone one-fourth; compact sandstone and pebble beds one-eighth; granite one-fortieth. Expressed in other words, one cubic yard of chalk or sand saturated with water would contain from 50 to 60 gallons of water, and an area of one acre three feet thick would contain about 260,000 gallons.

Except in depressions in the impervious substratum which have no outlet, the water in the subsoil is in constant motion, travelling towards the outflow. The rate of this movement is affected by the porosity of the ground, its slope, freedom of outlet, and many other factors. At Munich Professor Pettenkofer finds that the subsoil water moves towards the Isar at a rate of about 15 feet per day, whilst at Berlin the movement towards the Spree is barely perceptible. At Buda-Pesth the mean rate, according to Fodor, is 174 feet daily. The height of the subsoil water can be ascertained from the level of the water in the wells, and its variations will be indicated by the rise and fall of the water-level. This underground sheet of water may be of considerable extent, but its surface is not necessarily or even usually horizontal. It will slope towards the outlet, not uniformly, but with a curved surface. When water is abstracted at any point, as from a well, a portion of the water in the subsoil around drains into the well to replace that removed. The water-level for a certain distance is lowered, the curved surface sloping less and less as it recedes from the well (Fig. 13). The extent of area drained will vary with the degree to which the level of the water in the well is depressed, and with the permeability of the subsoil.

The whole of the rain falling upon a pervious soil does not percolate into it. Some will run off the surface, the amount varying with the slope and the nature of the

surface; some will be lost by evaporation, not only from the surface of the ground, but also from the leaves of herbs and trees. Dr. Dalton, at Manchester, found that only 25 per cent. of the rainfall percolated to a depth of 3 feet. Mr. Dickenson, at King's Langley, on a grass-covered gravelly loam, found that 42.4 per cent. reached that depth. Dr. Gilbert and Mr. Lawes, at Rothamstead, found that about 37 per cent. was collected at a depth of 20 inches, 36 per cent. at 40 inches, and 29 per cent. at 60 inches. Since the loss by evaporation in the summer is very great, little or no water may reach the underground reservoir during the warmer months (April to September). At Nash Mills, Hemel Hempstead, as an average of twenty-nine years' observations, the percolation in summer was found to be about 14 per cent., in winter 61 per cent., during the whole year 37 per cent. The soil here was chalky. On loose sands and gravel a much larger proportion would undoubtedly percolate, whilst in sandstones probably only about 25 per cent., and in limestones even a smaller quantity, would reach the ground water. The most favourable watershed is one which is fairly level, sandy or gravelly, and having few or no outlets; so that nearly all the water which percolates goes to increase the underground supply. Where the outlets are free, naturally the store of water will never be so large, since it is being constantly drained away.

Water is obtained from the subsoil by driving tubes or by sinking wells, and these may have galleries driven in various directions to increase the supply. The permanent yield of such a well will depend upon the area of the watershed by which the water is collected and the porosity of the subsoil. During dry weather the pumping operations will lower the level of the water and provide space for the water which will percolate during the wet season. To obtain a permanent supply of a fixed quantity of water, the proportion of the rain falling upon the contributing

area which can be collected must be equal to the quantity which it is desired to abstract. If the area of the watershed draining towards the proposed well be known, and the rainfall, the depth of ground water required to furnish a given daily supply may be approximately calculated. Let us assume that the rainfall records prove that 120 days' storage is required, and that the amount of water to be raised daily is 250,000 gallons, and that the subsoil is sand or gravel. Such a subsoil, when saturated, will contain about 35 per cent. of water; but the whole of this cannot be removed, only about 25 per cent. will run out when the water-level is lowered. In order to obtain this 250,000 gallons daily it will be found by calculation that it is necessary to have storage equivalent to 40 acres of ground, in which the water-level can be lowered 9 feet. If a superficial examination renders it probable that this amount of storage is available, a series of tests must be carried out to confirm it. For this purpose a number of test wells are driven during the dry season, and the change produced by long-continued pumping observed. The depth to which the water surface is lowered at the wells and at various distances from the wells will furnish the engineer with the required information.

The water from so-called shallow wells is subsoil water, and in most villages and nearly all rural districts such wells are the chief source from which water is derived. As a well only drains the ground for a limited distance around, where a larger supply is required other wells must be sunk or galleries be driven in various directions below the ground water level. On gently sloping ground a chain of wells may be sunk and connected together. In a valley through which flows a stream liable to pollution, pure water may sometimes be obtained by sinking wells along the foot of the hills, and so intercepting the ground water on its way to the stream. If the bed of the stream is formed of permeable rock, it will be saturated with water flowing slowly in the same direction as the stream. Such a sub-

terranean river may even convey more water than the visible stream. In the Thames valley it is estimated that the flow beneath the river considerably exceeds that of the river itself. In seasons of drought the subterranean flow may continue long after the bed of the stream has become dry, and at such times water may often be obtained by sinking a well. In galleries sunk along the course of streams or near the borders of lakes, where the subsoil is pervious, when the level of the water in the galleries is lowered below that of the surface of the stream by pumping or in any other way, water may flow from the river or lake into the galleries. Percolation outwards through the silt or mud at the bottom of rivers and pools can only take place slowly, and no definite measurements have ever been obtained of the amount. Where the quantity of water removed from the galleries does not reduce the level below that of the free water surface, the whole supply is derived from the ground water intercepted on its way to the stream, and only when the level is reduced below the free water surface is the supply supplemented by backward percolation.

The quality of subsoil water will vary with the character of the subsoil and the proximity to human habitations. In the chalk, lias, oolite, sandstone, and limestone districts the water will be hard, but the most ancient rocks, the Yoredale and millstone grits, and sands and gravels generally, yield soft water, if uncontaminated. The living earth has such remarkable powers of purification and filtration, and the subsoil beneath is so effective a filter, that natural ground water is almost free from germs (often it is absolutely free) and from organic matter. This natural process of purification will be described more fully in a later section. As usually derived from shallow wells, the subsoil water is almost invariably subject to contamination. The Commissioners appointed to examine the Domestic Water Supply of Great Britain reported that the most dangerous water is "shallow well water, when the wells are situated,

as is usually the case, near privies, drains, or cesspools. Such water often consists largely of the leakage and soakage from receptacles for human excrements; but, notwithstanding the presence of these disgusting and dangerous matters, it is generally bright, sparkling, and palatable." In Table IV. the highest and lowest results are given of the analysis of large numbers of waters from various geological sources. The majority of the samples, however, were very impure, and the lowest results only can be considered typical of pure water from these sources. Table III. contains recent analyses of a number of town water supplies derived from the subsoil. It will be observed that in many cases nitrates (as indicated by the nitric nitrogen) are present in considerable amount, and as these salts are derived from the oxidation of organic matter, such as sewage, manure, decaying vegetables, etc., waters containing such quantities of nitrates are often looked upon with considerable suspicion, and some chemists, relying upon their analytical results alone absolutely condemn these waters as dangerous to health. Koch,* comparing the processes of artificial and natural filtration, says: "As a rule, the soil is of a material much more finely granulated than the comparatively coarse-grained sand of the filter, and it is fair to expect that the subsoil water, after passing the sufficiently thick layers of this finely granulated soil, will be either very poor in micro-organisms, or quite free from them. This is confirmed by the investigations of C. Fraenkel, who has shown that subsoil water, even in a soil which has been much and for a long period contaminated, as is the case in Berlin, is quite free from germs. In other places the same results have followed from investigations made on this point. We have, therefore, no reason to keep out of consumption the subsoil water, which can be found nearly everywhere. On the contrary, we cannot find a better-filtered water and one more protected against infection. The only difficulty is to

* *Water Filtration and Cholera.* Translated by A. J. A. Ball.

bring this perfectly purified water into consumption without its being later on again contaminated and infected. In this respect great errors are still most inexplicably made everywhere." Wells as ordinarily constructed yield polluted water because no attempt is made to keep out surface water. Not only can the pure water enter at the bottom of the well, but the less perfectly purified can enter at the sides, and the impure surface water can gain access at the top. Often the wells are left open, and so unprotected that filth can be washed in with every rainfall, or, if covered, the dome is not water-tight, nor the ground above solid, nor of such a character or of such a depth as to purify the water passing through it. Drains of most primitive construction are often placed near to carry away the waste water from the pump, but used also for slop water of all kinds. Waters from such wells are notoriously liable to become infected, and have often caused outbreaks of typhoid fever and cholera. The proper construction of wells and the alteration of existing wells, so as to render them safe, are subjects of such vital importance that they will be discussed in a special chapter. Koch is so convinced of the absolute nature of the security from the danger of infection afforded by the use of subsoil water properly collected and stored, that he has proposed that the Berlin waterworks should be so altered as to supply the city with subsoil water only. Buda-Pesth derives its water supply from the subsoil along the banks of the Danube, in which a chain of wells is sunk, and the outbreak of cholera in 1893 was attributed to the use of this water.

In the State of Massachusetts, forty-two towns varying in population from 2,000 to 25,000 have public water supplies taken from the ground. The largest supplies are taken from localities in the vicinity of large bodies or streams of water. At Newton nearly 2,000,000 gallons of water are pumped daily from galleries extending for about three-quarters of a mile along the course of the river. At Waltham a well 40 feet in diameter is believed to be

capable of yielding 1,500,000 gallons daily in a dry season. Malden and Revere may be cited as examples of towns supplied exclusively with subsoil water, not supplemented by water percolating from lakes or streams.* "At Malden the amount pumped in 1890, 746,446 gallons daily, represented a collection of 9.7 inches (or 20 per cent. of the total rainfall of 49 inches) upon a direct watershed estimated at 1.61 square miles. At Revere the pumping for the year, 465,491 gallons daily, represented a collection of 12.5 inches (25 per cent. of the total rainfall of 50 inches) upon a watershed of 0.78 square mile." But "it is probable that the amount which has been pumped is more than could be pumped after one or two years of low rainfall. At Revere particularly, experience has shown that the storage capacity of the ground is very large, so that when the water-table is reduced to a very low level during the summer, the ground will not fill before the next summer, unless the amount of rainfall is above the average."

Where it is desired to obtain water from the porous subsoil, the direction of the flow of the ground water must be ascertained. This will be towards the springs, lakes, streams, or rivers forming the outflow. The ground water will have its highest level at the point most distant from the outflow, but most water will be obtainable near the outflow, unless the porous subsoil rests in a depression in the impervious rocks beneath, when most water can be procured where the depression is greatest. In an inhabited district the purest water will be found on that side which is farthest from the outflow, since all the impurities entering the subsoil will be carried in the direction of flow of the underground water. For this reason a pure water may sometimes be found at one side of a house, when that from the opposite side is polluted. Where a patch of gravel is bounded by streams on two sides, the ground water will be travelling in both directions, and that at one side may be

* *Report of State Board of Health*, 1890.

much less impure than that from the other. Thus in Fig. 6, if the village stand upon one side of the hill, it will affect only the ground water at that side, the water on the opposite side escaping contamination. The extraordinary extent to which the subsoil water can be affected by pollution from inhabited houses, highly cultivated land, etc., is indicated by the analyses given in Table IV. When examining recently the water from a gravel patch about one square mile in extent, and with a population of about 1,400 persons upon it, I found that the water along three sides of the patch was remarkably constant and uniform in composition, and very free from organic impurity, whilst that from the neighbourhood of the village, and between the village and the river, the principal outflow, varied considerably, and was more or less impure. In Table III. the analyses, Writtle, Nos. 1, 2, and 3, are of waters taken from the gravel at the three first-mentioned sides; Nos. 4, 5, and 6 are of water from wells in the village. The difference is entirely due to the soakage of slop-water, sewage from defective drains, sewers, cesspits, and cesspools, into the subsoil. In some cases the filth had been very fully oxidised before reaching the well, in others this oxidation was not nearly so complete. Such waters are, of course, quite unfit for domestic use. Where the surface soil has been removed, as in the neighbourhood of inhabited houses, the purifying influence of the living earth is lost, and where the porous stratum of subsoil is thin, the purification by oxidation and filtration is but limited. Where both these conditions occur, the subsoil water must of necessity be very impure. Koch's eulogy of the subsoil as a source of water supply must therefore be limited to those districts in which the population is scattered, and the subsoil of sufficient depth to secure efficient filtration and purification. Where both these conditions obtain, the ground may yield a water of the highest quality, but where these conditions are not fulfilled, there will always be impurity and risk.

TABLE III.

SUBSOIL OR GROUND WATER.

(Recent Analyses of Public and Other Supplies.)

Town.	Geological Formation.	Physical Properties.	In Grains per Gallon. Total Solids	Nitric Nitrogen	Chlorine	Temporary Hardness	Total Hardness.	In Parts per Million. Free Ammonia.	Organic Ammonia.	Nitrites.	Oxygen used in 4 hours.	Analyst.
Clown	Mag. Limestone	Many organisms	38·5	·21	2·4	5·5	11·5	·013	·06	·0	...	Dr. Barwise.
Saffron Walden	Chalk	Colourless	46 0	·95	2·6	18·5	23·0	·03	·03	·0	·27	Dr. Thresh.
Near Norwich	Gravel over Chalk	,,	37·0	·13	4 0	6·5	14·0	·08	·10	·0	·94	,,
Stroud (Goring's Well)	Inferior Oolite	,,	25·0	·27	1·8	9·0	16·0	·00	·03	·0	·93	,,
Near Stroud	Gravel on Upper Lias	,,	57 0	·93	6·2	26·0	26·0	·00	·06	·0	·44	,,
W. Worthing (1886)	Chalk	Nearly colourless	23·8	·43	2·6	13·5	19·0	·00	·015	...	·15	Dr. Dupré.
Poole	Bagshot Sand	Colourless	6·5	...	2·4		...	·00	·05	...	...	Dr. C. Leach.
Evesham	Oolite, Cotswold Hills	,,	17·0	·35	·9	11·5	11·5	·00	·14	...	...	Dr. Fosbroke.

N. Rawtenstall	Sandstone	Colourless	7 6	·66	1·4	...	...	·00	·04	...	...	Dr. Campbell Brown.
Southampton	Chalk	,,	22·0	·25	1·1	16·0	18·0	·05	...	...	...	Dr. Percy Frankland.
Elbourne	Devonian Red Sandstone	Grayish	10·0	·02	2·8	·0	6·0	·012	·03	·0	...	Dr. E. H. Young.
Ware	Chalk	...	28·0	·01	1·75	18·5	21·5	·00	·04	·0	·0	Dr. G. Turner.
Bishop Stortford	,,	...	30·0	trace	1·7	17·0	20·0	·025	·03	·0		,,
Ingatestone	Sand	Trace of Iron yellowish	18·0	·14	2·2	3·0	5·5	·00	·01	·0	·30	Dr. Thresh.
Burnham	Gravel	Colourless	34·5	·84	3·6	7·0	15·0	·00	·04	·0	·50	,,
Massachusetts:												
Revere	...	,,	...	·12	2·3	...		·01	·012	trace	...	...
Walden	...	,,	12·6	·35	1·5	...	5·5	·00	·016	·0	...	...
Waltham	...	,,		·03	·3	...	...	·00	·012	·0	...	...
Newton	...	,,	...	·02	·2	..	...	·00	·01	·0	...	...
Village of Writtle 1.	Gravel	Colourless	28·0	·33	1·5	16·5	20·0	·01	·02	·0	·025	Dr. Thresh.
2.	,,	,,	32·0	·45	2·3	16·0	18·0	·00	·05	·0	·875	,,
3.	,,	,,	37·0	·31	2·6	19·0	21·0	·00	·01	·0	·13	,,
4.	,,	,,	109·0	3·97	11·0	25·0	36·0	·04	·05	·0	·78	,,
5.	,,	Turbid and yellow	130·0	4·65	14·3	22·0	40·0	·00	·12	·0	1·56	,
6.	,,	,,	73·0	2·5	4·9	22·0	27·0	·08	·05	trace	1·60	,,

TABLE IV.

Shallow Well (Subsoil) Water from various Geological Sources.

(Compiled from Report of Royal Commission on Domestic Water Supplies of Great Britain, 1874.)

In Grains per Gallon.

	Total Solids.		Nitric Nitrogen.		Chlorine.		Temporary Hardness.		Total Hardness.	
	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest
In or upon Silurian Rocks and Gneiss	70·1	2·7	1·7	·02	12·0	·6	15·6	·0	29·1	2·4
,, Devonian Rocks	73·6	8·5	2 9	·015	11·9	1·0	15·0	·0	39·0	3·5
,, Yoredale and Millstone Grit	93 5	4·1	3·5	·004	9·1	·4	26·0	·0	63·0	2·0
,, Coal Measures	154·6	6·6	7·0	·0	20·3	·7	20·0	·0	98·0	2·4
,, Mountain and Magnesian Limestone	76·2	32·1	3·4	·37	9·3	1·7	28·0	12·6	62·0	28·5
,, New Red Sandstone	168·1	14·4	10 3	·02	27·3	1·0	29·5	·0	89·0	12·0
,, Lias	215·0	26·0	13 9	·0	28·3	1·2	28·0	·0	82·0	2·0
,, Oolite	189·0	22·0	8·5	·0	31·0	1·1	30·0	13·0	55·0	16·0
,, Upper and Lower Greensand and Wealden Beds	267·0	7·4	4·7	·0	58·0	1·5	25·0	·1	56·0	2·7
,, Chalk	111·0	23·0	4·4	·42	20·0	1·3	25·0	8·4	50·0	16·7
In Gravel on London Clay	277·0	22·0	18·1	·0	24·2	1·3	34·0	·0	134·0	10·0
,, Bagshot Beds	201·0	16·0	12·5	·0	21·8	1·7	15·0	3·7	92·0	9·0
,, Fluvio-Marine series	46·0	5·7	2·5	·0	5·0	1·7	8·5	·0	25·5	3·2
,, Alluvium and Gravel	225·0	20·0	7·9	·0	25·3	1·2	25·5	1·9	107·0	3·0

CHAPTER V.

NATURAL SPRING WATERS.

Spring waters have always been held in high repute as sources of domestic supply, and justly so, since springs yield as a rule waters of a high degree of organic purity. As they gush from the ground also they can easily be utilised, no form of machine being necessary to raise the water. Although usually so free from organic matter, many springs contain inorganic constituents of such a quality, or in such quantity, as to confer upon them medicinal properties which man has not been slow to utilise. Numerous springs of this kind are known which have enjoyed a high reputation for their curative properties from time immemorial. Some again yield water of delightful coldness throughout all seasons of the year, whilst others yield warm, hot, and even boiling water. Certain springs also appear to be perennial, the flow being constant, or apparently so, even during periods of excessive drought, when streams have ceased to flow and wells to yield. For these reasons the origin of springs had always been, until within a comparatively recent period a cause of wonder and speculation. The facts brought to light by the study of geology and hydrology have, however, robbed them of much of their mystery; but the source of certain constituents and the cause of the high temperature of the water yielded by many springs still give rise to much discussion. The overflowing water varies in volume from that of the tiniest rivulet to that of a river of considerable magnitude,

yielding millions of gallons per day as the Sorgue and Loiret in France, the Manifold and Hamps in Staffordshire, and the river Aire at Malham Cove in Yorkshire. The pressure on the water may only be just sufficient to cause it to overflow upon the ground, or it may be so great, and applied in such a direction as to throw it vertically upwards for even 50 or 100 feet above the level of the surrounding surface. Not only also do springs arise in valleys and depressions on the earth's surface, but sometimes upon or near the summits of hills of considerable elevation. Such springs, if of any large volume, are often of great value, since the water can be conveyed by gravitation to any point at a lower level where a supply is required.

Springs are so varied in character that it is difficult to classify them. According to the temperature of the water, we have cold springs, hot or thermal springs, and boiling springs or geysers. According to the direction of flow, we have descending springs and ascending springs; and according as they arise from superficial or buried strata, we have land springs and deep springs. The latter division is the most suitable for our purpose, though certain springs in mountainous districts can scarcely be included under either class. These are springs originating from elevated lakes, or by the melting of the snow and ice of glaciers. In the Alps such springs abound. The Dauben See, a lake on the Gemmi, at an elevation of 7,000 feet, has no visible outlet; but about 1,000 feet lower upwards of fifty springs are found, which appear to be fed by the lake. By the melting of glaciers resting on fissured rocks, the water traverses the fissures and issues as springs in the valleys below. Land springs proper occur where the impervious stratum supporting the pervious subsoil outcrops, providing the outcrop be at a lower level than that of the subsoil water. Where the patch of pervious ground is small in extent and of little depth, the springs arising therefrom will be "fleet," or

variable, markedly affected by the rainfall, ceasing to flow during a drought and flowing freely after heavy rains. The constancy of flow increases with the extent of the collecting surface and the depth and permeability of the subsoil. The freedom of outlet also is a factor, for if very free the volume of the spring will be more readily affected by the rainfall than if the outlet be more restricted. Where the porous subsoil fills up a hollow in the impervious rock beneath, the ground water level may, during long-continued droughts, sink below the level of the outcrop, and it may require a series of wet years to again raise the level to such a height as to cause the springs to flow. Many such "intermittent" springs are known, *e.g.* the Caterham springs and the Hertfordshire Bourne. The latter appears at intervals of four to seven years (Dr. Attfield). Springs of this character are obviously quite unsuitable for public water supplies, as they are not to be depended upon for any lengthened period. Deep and ascending springs are usually much more constant than land and descending springs, since they are fed from subterranean sources often of vast extent. The water also has undergone more complete filtration, and any organic matter originally contained in the water becomes completely oxidised, so that such springs generally yield water of a high degree of organic purity. The rain which feeds the springs may fall upon the absorbing surface many miles away. Passing into the pervious rock, it follows the direction of this stratum, which first dips downwards under some impervious formation, and later outcrops at a lower level than that of the absorbing surface. In the chalk and other fissured rocks the water travels chiefly, if not almost exclusively, along the lines of fissure, and where the rock is soluble these fissures may become enlarged, until in time caverns are formed, some of which are of great extent and form subterranean reservoirs of water. At great depths water probably meets with carbonic acid gas under pressure, which it absorbs. As the

temperature of the earth increases with the distance from the surface (on an average the temperature increases 1° C. for every 106 feet descended), this elevated temperature and the excess of carbonic acid increase greatly the solvent powers of the water, and possibly explain the formation of such vast caverns, and also the greater richness of most of these springs in mineral constituents. Water may be thrown out, not only at the natural outcrop of such a pervious stratum, but by faults, or by the filling up of fissures with some impervious material impeding the natural flow of the water and directing it upwards to the surface.

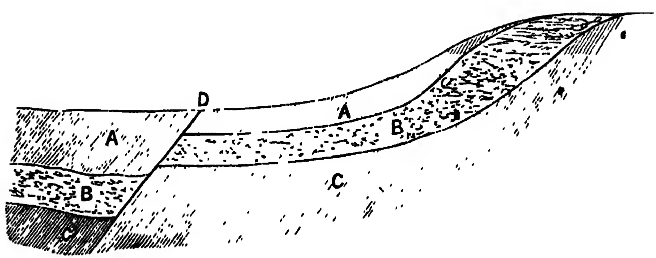

FIG. 7.

Artificial springs are formed wherever a communication is made between the surface of the ground and the water imprisoned under pressure in a pervious stratum lying between two impervious formations. Where the pressure is sufficiently great the water overflows. This is the principle of the Artesian well, which, however, will be considered later as a variety of "deep" well. In some cases, however, nature has provided such a communication between the surface and the water beneath, by means of a fault, giving rise to a deep or ascending spring.

Fig. 7 shows how such a spring may be formed. A represents the superficial stratum of impervious rock, C the deep impervious formation, B the intermediate pervious bed collecting the rainfall on its exposed surface at an

elevation considerably above the surface at the point of faulting, D. It is obvious that the depression of the layer A prevents the water stored in B passing beyond the fault, and it must therefore accumulate until the whole of that portion of B to the right of the fault becomes saturated, unless some means of escape is provided. The violence, however, which produces a fault necessarily causes irregularities in the disrupted surfaces, and the fissures may extend from the surface down to B. As the water-level in the latter rises it will fill these crevices, and finally, when the level reached is above that of the ground at D, a spring will result. Of course the fissures above alluded to may extend downward so as to restore the connection between the two portions of the pervious stratum, in which case no spring will be formed, unless B outcrops at both sides above the level of D. In the latter case the spring will be fed from both sides, and therefore be of increased volume. If the layer A be of clay, or a rock of similar nature, fissures would not be formed, and the fault would not therefore give rise to a spring. The most favourable conditions exist when A is a hard rock and C is of a clayey nature. The two portions of B will then be completely disconnected, and the imprisoned waters must travel along the line of fault towards the surface. The springs at Clifton and Matlock are thus produced, and probably also the equally noted springs at Buxton, Bath, and Cheltenham.

The amount of water yielded by such springs depends upon the amount of rainfall absorbed by the collecting surface, and is therefore proportional to the area of such surface. The character of the water depends upon the nature of the rocks with which it comes in contact in its underground course. For example, if it passes through beds of rock salt, it will take up large quantities of that substance; if through beds of gypsum, it will contain much sulphate of lime.

Whether the quantity of water yielded by a spring or

springs will be sufficient for the supply of a town or village can only be ascertained by actual measurements of the flow made at intervals through a considerable period, but it may be surmised from other evidence as to the constancy of the flow. A careful study of the geology of the district is also necessary, and a knowledge of the situation, area, and character of the gathering ground, and of the rainfall thereupon, is also essential. It must not be forgotten also that where the water chiefly travels through fissures in the rocks impurities may be carried long distances without undergoing oxidation or other change which will render them harmless. In the account of epidemics produced by polluted waters, examples will be given of such pollution and of disease produced thereby. The flow from natural springs is rarely so copious or so constant as to render them suitable sources from which to supply towns of any magnitude. Bristol originally derived the whole of its supply from springs at Chewton Mendip, which yielded a minimum of 2,000,000 gallons of water a day for a long period. The fluctuations increased, and at length became so serious that the supply had to be supplemented from other sources. Deep springs are obviously preferable to land springs, both on account of their greater constancy and lesser liability to pollution. The water also is usually more brilliant, sparkling, and palatable, and is generally preferred for domestic purposes, unless the hardness is excessive, to water from any other source. Amongst rural communities a preference is usually shown for natural springs with natural surroundings, and objections are often raised to any works of an artificial character being carried out for protecting the water, or for doing anything more than is absolutely necessary to enable vessels to be filled. Where a community is to be supplied, a reservoir is necessary, but the capacity need rarely exceed that of twenty-four hours' supply. A larger reservoir is only required when the flow at certain periods is in excess of

the demand, whilst at other periods it is insufficient to meet all requirements. The amount of storage necessary to obtain a constant and ample supply must be determined from a consideration of all the circumstances affecting the particular case.

Springs can often be utilised very economically for supplying mansions and small villages with water, even when the latter are at a greater elevation than the former, providing the flow be sufficient to work a ram, turbine, or other similar form of pumping-engine. As only a small proportion of the water is lifted by the fall of the remainder, this surplus water will be available for supplying houses at a lower level than that of the overflow from the ram or turbine. In this way the water yielded by a spring on the side of a hill may be utilised for supplying water to the inhabitants on the hill above as well as to those in the valley beneath.

The following quotations from a report by W. Whitaker, F.R.S., on the "Best Source for a Water Supply to the Town of King's Lynn," contain many points of interest, since they bear upon a number of questions which have to be considered when a scheme for supplying a town with water is being discussed (King's Lynn is a town at the mouth of the Wash, with a population of 18,265):—"Lynn is one of those towns which cannot get its water supply within its own borders. A thick bed of clay underlies the marsh-silt that forms the surface, not only of the town itself, but also in the greater part of the neighbourhood, where this (and other alluvial beds) have a wide spread along the main valley, with comparatively narrow inlets up the tributary valleys.

"These clays have been proved, by a boring in the northern part of the town, to go down to a depth of about 680 feet, and then, without reaching the bottom, leaving it uncertain how much deeper clay may go. Now if a bed usually of a water-bearing character should occur at some

little further depth, it is doubtful whether a large supply would be got, at all events by boring, for it is often found that a thick mass of overlying beds tends to close the fissures, etc., in underlying beds that, nearer the surface, are quite permeable. It can readily be understood that the weight of a mass of clay some 700 feet is very great, and is likely to have an effect on any limestone or sand beneath.

"Clearly, therefore, it is needless to consider the question of boring for deep-seated water in the town. Very small quantities of water might possibly be got, from occasional and local sandy beds in the clays; but these would be useless for a public supply.

"Having then to go outside the municipal boundary, it is natural to consider, firstly, the nearest source of supply. This is the lower greensand (as it is somewhat unfortunately called, green being generally an exceptional colour in it), a formation which in this part of the country consists of variously-coloured sand, sometimes cemented (by iron oxide) into the ferruginous stone known as carstone, and occasionally with a thin bed of clay in the middle part.

"It has a fairly broad outcrop (to over five miles) eastward of Lynn; but this is much indented by alluvial deposits up the valley-bottoms, and there are also many cappings of drift clays over the higher parts and down some of the slopes, even to their bases. Nevertheless, the formation being for the most part highly permeable, much water must sink into it.

"The underlying Kimmeridge clay crops out in places on the west, by the border of the alluvial lands, the gentle dip of the beds being easterly; but there are no powerful springs, and consequently, to get a large supply of water from the lower greensand, it would not do to sink near Lynn—that is, toward the boundary of the formation—but wells would have to be made a good way to the east, so as to command the underground flow of water from a large area."

Dr. Whitaker then expresses doubt as to whether one or even two wells would yield a sufficient supply, as in sands underground galleries cannot be cut, as in limestones, chalk, etc. Wells sunk in sand also often get silted up and then require clearing out. The lower greensand is usually ferruginous, and does not therefore yield a water of high quality. Passing on to the chalk formation and the water obtainable therefrom, Dr. Whitaker says:—

"Much of the water falling on the chalk sinks into it, and of this a part finds its way downward, until at some depth the chalk is saturated and can hold no more. The level of saturation varies roughly with that of the ground, being higher at the hills on the east than at the slope toward the outcrop of the underlying gault; the reason of the difference of level being the frictional resistance to the flow of the water through the chalk. The underground water-slope in the chalk of the immediate neighbourhood being westward, the springs are therefore merely the natural outflow of the water-charged chalk, the water finding its way out at the lowest available places, the slowness of percolation through the rock making the springs constant, though of course varying in amount, instead of their being very great at one time (after heavy rain) and dry at another, as would be the case if the water flowed through quickly.

"The water of these springs is, by nature, of the best quality; its only defect can be hardness, and this can be got rid of to any reasonable extent, if needful; but alas! nature has not been left alone; man has changed the state of things, and not for the better! Of the three chief sources, two have been polluted in a most unlucky way (one by a churchyard, and the other by the filth of a farmyard).

"The intermediate spring at Sow's Head is away from all buildings. I agree with Mr. Silcock (the Borough Engineer) that it is to the chalk that Lynn should go for its water supply.

"Of the two schemes that he has brought before you to get this water, I must own to a partiality for the bigger one, for getting the water by means of a well and galleries, somewhere near and above Well Hall, which would intercept the water on its way to the spring, and for pumping it to a reservoir at the brow of the hill, about midway to Lynn, which certainly seems to be about the best site for a reservoir, there being a mass of boulder clay over the top of the hill.

"As, however, there seems to be no likelihood of large increase in the population of Lynn, the question of cost must lead one to look favourably on the other scheme, for taking water by gravitation from the Sow's Head Spring, after opening it out.

"I have no doubt that the work of cutting back and opening out that spring would result in a goodly increase of the outflow; but unfortunately we have no means of saying how large that increase would be, and so it would hardly do to adopt that scheme absolutely without some further knowledge. I think therefore that Mr. Silcock has wisely asked that some preliminary work should be done, at no great cost, to try the power of that spring. Of course with a spring supply you can only take what the spring gives you, whereas in pumping from a well you draw in water from around, creating an artificial inflow."

Excellent examples of the utilisation of natural springs for the supply of water to a number of small villages are the works recently carried out in the Chelmsford Rural Sanitary District by the Authorities' Surveyor, Mr. I. C. Smith, and in the adjoining Rural District of Maldon by Mr. H. G. Keywood, Surveyor and Engineer. These works are described in a later section.

In the *Massachusetts Report on Water Supplies* little reference is made to springs, since apparently no town is supplied from such a source. In the 1891 *Report*, however, it is stated that large quantities of spring water are sold

throughout the state, "particularly in cities and towns where the regular water supply is thought to be unsatisfactory, or where the water, as is not infrequently the case with surface water supplies in the summer time, has an unpleasant taste and odour." "There is also a large amount consumed in bottled form, as soda water and other effervescing drinks." Waters were examined from forty-five springs, and most of them found to be of the highest purity. Even those samples taken from populous districts and near sources of pollution showed that a high degree of purification had been effected by filtration through the ground.

The character of spring water depends chiefly upon its geological source. The water from a deep spring will naturally be characteristic of the stratum in which it is stored underground, and be little if at all affected by the more superficial formations through which it merely passes on its way to the surface. Bearing this in mind, the quality of the water obtainable from springs arising in various geological strata may be described in very few words. In all cases it is assumed that the water is free from pollution.

1. *Granite, Gneiss, and Silurian Rocks.*—Usually excellent in every way, their purity and softness rendering them admirably adapted for drinking, cooking, and washing purposes. The hardness rarely exceeds 7°, and is usually much less.
2. *Devonian Rocks and Old Red Sandstones.*—Very wholesome and palatable. The hardness varies considerably (2° to 21°). Usually they are fairly soft, but some samples are too hard for washing purposes.
3. *Mountain Limestone.*—Bright, colourless, and very palatable, but usually too hard for washing purposes. The average hardness is about 14°, but it may exceed 30°. In some the hardness is chiefly "temporary," in others "permanent."

4. *Yoredale Rocks, Millstone Grit, and Coal Measures.*—Generally wholesome. Average hardness about 10°, but varies from 2° to 18° or more.
5. *New Red Sandstone.*—Yields water abundantly, and of great purity—bright and sparkling. When not too hard it is excellently adapted for all domestic purposes. The "permanent" hardness usually exceeds the "temporary," and the total hardness varies from 6° to 24°, the average being about 13°.
6. *Lias.*—The water from this formation is usually so hard (the average is over 20°) that unless artificially softened it is not well adapted for domestic purposes. As the hardness is generally of the "temporary" character, it can easily be reduced by any of the lime processes.
7. *Oolites.*—Springs abound on this formation, and are often of immense volume. The water is excellent in quality, though invariably rather hard. The average hardness is 17°, the extremes about 12° and 27°. The hardness is almost entirely "temporary," and when excessive can readily be removed.
8. *Greensands, Upper and Lower.*—Although very palatable and wholesome, the water furnished by these sands varies much in character. The hardness may be less than 1° or upwards of 25°. As a rule it is chiefly temporary.
9. *Chalk.*—The water from chalk springs bears justly a great reputation for purity, brightness, and wholesomeness, though often the hardness is too great for washing purposes. It varies from 8° to 22°, with an average of 17°. Of course it is almost entirely due to carbonate of lime and can be readily removed where necessary.
10. *Gravel and Drift.*—Varies to an astonishing degree. The Bagshot gravels and sands usually furnish a soft water, whilst some gravels yield water of excessive

hardness. Land springs alone are formed in these superficial deposits, and the water generally contains more or less of the products of the oxidation of manurial matters which have been applied to the surface.

According to the Rivers Pollution Commissioners, the chalk, oolite, lower greensand, and new red sandstone are the best water-bearing strata in the kingdom; their water-holding capacity is very great, and the quality of the water excellent. Where they dip below any "impervious formation they are still charged with water and easily accessible to the boring rod." The most constant and largest springs are derived from the chalk, oolite, new red sandstone, millstone grit, and mountain limestone. In the two latter formations the water is contained chiefly in fissures (this is probably the case also with the chalk), and the flow from the springs therefore is more likely to be markedly affected by prolonged drought.

TABLE V.

ANALYSES OF SPRING WATERS FROM VARIOUS GEOLOGICAL SOURCES.

Town.	Geological Source.	Physical Characters.	In Grains per Gallon. Total Solids.	Nitric Nitrogen	Chlorine.	Temporary Hardness	Total Hardness.	In Parts per Million Free Ammonia.	Organic Ammonia.	Oxygen Absorbed.	Analyst.
St. Austell	Granite and Gneiss	Slightly turbid	4·5	·02	1·4	·4	9	·00	...	...	Dr. Frankland.
Melrose	Silurian Rocks	Clear	10·4	·05	·7	...	8·5	·01	03	...	M. Dechan.
Abergavenny	Old Red Sandstone	Almost Colourless	7·8	trace	·9	3·0	6·5	03	·02	·06	Mr. Duprè.
Chepstow	,,	Turbid	5·0	·05	·8	1·7	3·0	·01	·04	·43	Dr. Thresh.
Weston-Super-Mare	Mountain Limestone	Clear	77·0	·41	23·8	17·5	26·0	·00	·04	·37	,,
Totnes	,,	C. and C.	12·0	·01	1·5	2·0	5·2	·01	·03	1·43	Dr. W. Blyth.
Swansea	Millstone and Yoredale Rocks	,,	3·5	·08	1·0	·0	1·0	·02	·05	...	Dr. Davies.
Bristol	Triassic Conglomerate and M. Limestone	,,	22·6	·09	·8	13·0	19·0	·07	·03	·3	Dr. Wright.
Atherstone	New Red Sandstone	,,	35·0	·22	1·8	[illegible]	22·0	00	·01	...	...
Grantham	Inferior Oolite	,,	24·5	·54	1·1	12·5	14·5	·00	04	·64	Dr. Thresh.

Yeovil	Oolite	...	24·0		1·3		19·0	·01	·02	..	...
Cheltenham	,,	C. and C.	16·0	·37	·8	...	·	·01	·02	·00	Dr. Garrett.
Stroud—Public Spring	Upper Lias	,,	43·5	1·04	3·5	7·0	22·0	·00	·03	·24	Dr. Thresh.
New Brompton	Chalk	C. and C.	24·5	·28	1·9	16·5	21·0	·00	·01	·19	,,
King's Lynn, proposed supply	,,	,,	20·4	·42	·8	11·0	14·0	·00	...	...	Dr. P. Frankland.
Danbury	Gravel	,,	18·5	·72	1·9	1·5	6·0	·07	·02	·50	Dr. Thresh.
Southminster	,,	,,	17·5	1·14	2·0	1·75	6·0	·04	·04	·53	,,
Springfield	,,	,,	16·0	·85	1·8	2·5	6·0	·00	·05	·20	,,
Average of samples examined by R.P.C. 8 samples	Granite and Gneiss	Clear and palatable	4·2	0·7	1·2	·3	2·1	·01		...	
15 ,,	Silurian Rocks	,,	8·6	·13	1·3	1·0	4·8	·01	...		
22 ,,	Devonian Rocks and O. R. Sandstone	,,	17·5	·53	2·7	3·4	8·4	·01	...	...	
13 ,,	Mountain Limestone	,,	22·4	·16	3·2	7·6	14·0	·01	...		
8 ,,	Yoredale and Millstone Grit	,,	12·5	·12	1·2	4·5	8·6	·01	...	..	
14 ,,	Coal Measures	,,	15·4	·28	1·4	3·6	9·0	·01	..	..	
15 ,,	New Red Sandstone	,,	20·0	·23	1·5	5·6	13·0	·01	.	..	
7 ,,	Lias	,,	25·4	·33	1·7	15·0	21·0	·01	.	...	
35 ,,	Oolite	,,	21·0	·25	1·1	14·6	17·0	·01	...	...	
19 ,,	Greensands	,,	21·0	·23	2·1	9·5	14·0	·00	.	...	
30 ,,	Chalk	,,	21·0	·27	1·7	12·6	16·5	·01	...	...	
10 ,,	Drift and Gravel	,,	42·9	·25	1·9	12·6	26·0	·01	..	.	

CHAPTER VI.

DEEP-WELL WATERS.

THE term "deep" in reference to wells is somewhat ambiguous, since different writers attribute to it different meanings. By some, any well over 50 feet in depth is called "deep," whatever the character of the stratum in which it is sunk, or the strata through which it passes. By others the term is used without any reference to actual depth, but to imply that the well is sunk through some impervious stratum into a water-bearing formation lying beneath. Such writers regard all wells as "shallow," whatever their depth, if they are sunk into and yield water from a superficial stratum. Water in the interstices of a rock overlaid by an impervious formation must have travelled some distance (often many miles) from the outcrop upon which the rain furnishing it fell; hence filtration and oxidation is as a rule very perfect. But where a pervious formation is so thick that the water level is 50 feet below the ground surface, it is evident that in percolating to this depth the water will have become so purified as to approach the subterranean water above referred to in character. Such being the case, it is best to consider such deep superficial wells as "deep." Deep wells passing through impervious into pervious and water-bearing strata are best designated as Artesian, although this name is often reserved for those deep wells from which water actually overflows. The first wells of this character were probably sunk in China; they were common in the East at a very

early period. Centuries ago they were also sunk in the province of Artois in France. One such well there has undoubtedly yielded a continuous supply of water since the year 1126 A.D. At Grenelle in this province a large boring was commenced in 1835, and was carried to a depth of about 1,800 feet before the water-bearing sand was reached. The water then rushed in and rose some 60 feet above the surface of the ground, the flow being nearly 1,000,000 gallons per day. With the imperfect appliances of that period, the well took six years to bore. Artesium being the ancient name for Artois, all such wells have since been

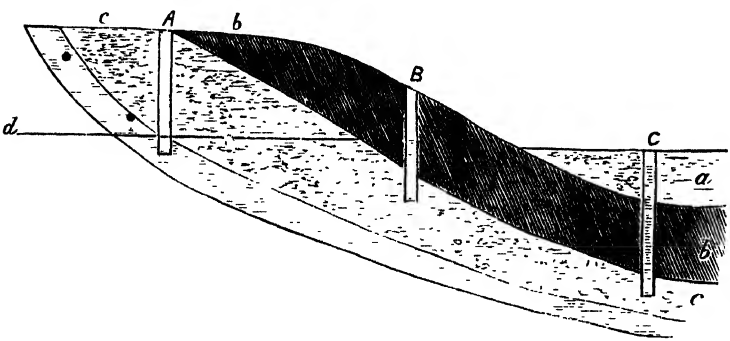

FIG. 8.

called Artesian. The various kinds of deep well are illustrated by the above diagram, Fig. 8.

The water-level in the formation *c* being at *d*, it is evident that a well sunk at A would not pass through the superficial impervious stratum *b*, yet would be deeper than the well sunk at B, passing through this formation to reach the same source of water. The level of the ground at C being considerably below the water-level *d*, water would overflow from the well at C. The latter, therefore, is a true Artesian well, or we may call it an overflowing Artesian well to distinguish it from B.

Very little consideration will render it obvious that

pervious strata which lie below the sea-level must retain within them all the water absorbed at their outcrop. Formations of this character, with extensive exposed surfaces, passing under other more superficial strata, may store enormous amounts of water, and if they do not reach too great a depth, which is rarely the case, water may be obtained from them by boring or sinking a well. The greater the depth to which the boring passes, the greater the supply of water obtainable. Thus in Fig. 8, as soon as the water-level in *c* became depressed by pumping from A, B, or C, below the bottom of A, that well would cease to yield. If the water-level became still more depressed B also might fail, whilst C would continue to furnish a supply. This only applies when the pumping at the lower level is withdrawing more water than is passing into the outcrop from the rainfall. When such is not the case, the effect of one well upon another, if some distance apart, will be inappreciable. If the whole of the pervious stratum *c* be not saturated with water, the conditions will be different, water will be travelling in the direction from A to C, either towards the sea, some river, or spring (unless, as occasionally may occur, there be no outlet), and the movement of the water present in the rock may be looked upon as analogous to that of a subterranean river, or as that of water in a cistern supplied at the top and being drawn off at the bottom. According to the cistern theory, pumping will reduce the level of the water without stopping the "leakage" from the bottom, whilst on the river theory pumping will chiefly affect the leakage, since abstraction of water from any point in a river must decrease the flow of water past that point. The two views were ably argued before the Royal Commission on Metropolitan Water Supply, and after hearing the evidence of Sir John Evans and Mr. Whitaker in favour of the "cistern" theory, and of Baldwin Latham in favour of the "river" theory, the Commissioners reported as follows:—

"We are of opinion that the analogy of a cistern is inaccurate and misleading when used in relation to streams at a considerable distance from the points where pumping is carried on. A waterworks well is itself a typical cistern; the pumps are not unfrequently submerged many feet, and when pumping commences it is the bottom water that is withdrawn, and in consequence of losing its support the upper water is proportionally lowered. . . . But in addition to this vertical and horizontal lowering (of the water surface) in the open well, there goes on simultaneously a lowering of a different character in the chalk around the well.

"Immediately adjoining and outside an unlined chalk well, the water lowers *pari passû* with that inside, but the same horizontal plane is not continued outwards. The water cannot pass through the crevices in the chalk to the well without a certain amount of fall or slope, this being necessary to overcome the friction of its passage. Hence the surface of the water in the emptying chalk rises from the well in all directions at a gradient more or less steep, in relation to the openness or closeness of the passages. These slopes will nowhere probably form a symmetrical or regular cone-shaped depression having the well as its centre, but slopes at varying angles modified by circumstances are undoubtedly required if the supply to a well is to be maintained whilst pumping is going on.

"It is only necessary to follow out this idea to a distance of miles from the well to realise clearly that the cistern theory is untenable. In the open well the upper water is supported directly by that below it, and when the support is removed the surface is immediately and vertically depressed. Out in the body of the chalk the upper water is only partially supported by that below it, and mainly by the chalk in and upon which it lies and flows; and this being so, the analogy of a river is much more apt and accurate than that of a cistern. Mr. Baldwin Latham and other witnesses were therefore more nearly right than Sir

John Evans, when they said that pumping from a well tapping an underground stream flowing in a known direction mainly affected the water below the well, and had little effect on that above the well."

The same reasoning applies not only to the chalk, but also to all porous underground strata containing water under similar conditions.

But few deep wells are sunk into the Devonian rocks, millstone grit, coal measures, or magnesian limestone, the probability of obtaining water therefrom being in most cases very problematical. The new red sandstone, oolites, and chalk are the great subterranean water-bearing strata, the lias, greensands, Hastings, and Thanet sands having smaller outcrops, and being much thinner, and not so certainly continuous, yield much more limited supplies. The new red sandstone is an exceedingly effectual filtering medium, and from the great extent of this formation vast quantities of the purest water are stored in it, and often can be rendered available at a comparatively slight expense. The oolites, according to the R. P. C., "contain vast volumes of magnificent water stored in their pores and fissures . . . and it cannot be doubted that a considerable proportion of this could be secured for domestic supply in its pristine condition of purity at a moderate cost." The chalk formation is one of the most absorbent; therefore a large proportion of the rainfall upon its outcrop passes into it and becomes thoroughly filtered and purified. The R. P. C. found the deep-well waters from the chalk "almost invariably colourless, palatable, and brilliantly clear." "The chalk," they say, "constitutes magnificent underground reservoirs, in which vast volumes of water are not only rendered and kept pure, but stored and preserved at a uniform temperature of about 10° C. (50° F.), so as to be cool and refreshing in summer, and far removed from the freezing-point in winter. It would probably be impossible to devise, even regardless of expense, any artificial arrangement for the storage of water that could secure more

favourable conditions than those naturally and gratuitously afforded by the chalk, and there is reason to believe that the more this stratum is drawn upon for its abundant and excellent water the better will its qualities as a storage medium become. Every 1,000,000 gallons of water abstracted from the chalk carries with it in solution, on an average, $1\frac{1}{4}$ tons of chalk, through which it has percolated, and this makes room for an additional volume of about 110 gallons of water. The porosity and sponginess of the chalk must therefore go on augmenting, and the yield from the wells judiciously sunk ought within certain limits to increase with their age." Strange as it may appear, this does not apply to waters from the chalk in certain districts which, instead of being hard, as is usually the case, are exceptionally soft, containing sometimes not more than two grains of chalk in solution in each gallon. Such exceptions prove that the underground sheet of water is not continuous. As previously explained, this is occasioned chiefly by faults interrupting the continuity of the strata, and such faults may seriously affect the supply obtainable from any particular well. Besides such faults, various foldings and irregularities often occur, dividing and subdividing the subterranean reservoir, cutting off more or less completely one compartment from another, and limiting the supply. Before sinking a deep well, therefore, many points have to be carefully considered if the possibilities of failure are to be reduced to a minimum.

The chief are:—

1. The extent and character of the absorbing area or outcrop, whether bare or covered with drift, whether level, undulating, or hilly; its elevation above the district proposed to be supplied by the wells; the density of the population upon it, or discharging their sewage thereon.—Notwithstanding the purifying action of porous rock, it is not desirable to have a dense population upon the outcrop, as in course

of time the water may become affected. Many wells have had to be closed for this reason. At Liverpool, for instance, several deep wells belonging to the Corporation became polluted by the population on the collecting area, and had to be abandoned. Where the subterranean water is chiefly collected in and travels through fissures this danger is accentuated. The extent of the absorbing area is often difficult to determine, as implicit reliance cannot be placed on maps. The sections at the surface, by which the geological structure was determined at the time of the survey, are occasionally misleading.

2. The average rainfall for a number of years.—This being known, and the nature of the surface determined, a rough estimate of the amount of water absorbed may be formed (*vide* Chap. XVII.). But the outcrop may receive the drainage of a neighbouring impervious area, or, on the other hand, the contour or surface of the outcrop may be such as to throw off an unusual proportion of the rainfall, or much of that absorbed may flow away from springs. The levels of the springs must be studied to ascertain the direction of flow of the underground water, and their positions may lead to important inferences with reference to the continuity or otherwise of the water-bearing stratum, the presence of faults, crumblings, or other irregularities.

3. The continuity of the water-bearing strata and their superficial area and thickness.—The maps issued by the Geological Survey show the position and throw of all known faults, but trial bores have frequently to be made to ascertain whether others exist, unless their absence is proved by existing wells. The study of data obtained from recorded well sections, or by the results of trial bores, will give an idea of the thickness and extent of the porous stratum. The thickness may vary considerably. Thus the chalk at

Norwich is nearly 1,200 feet thick, in Wiltshire 800 feet, in Surrey 350 to 400 feet, in East Kent 800 feet, at Harwich 888 feet, at Kentish Town 640 feet. The lower greensand which lies beneath the chalk has a thickness of probably 600 feet in the Isle of Wight, but it rapidly thins away and appears to be absent under London. As an instance of the difficulties met with in determining the extent of an underground water-bearing deposit, and of the unreliability of maps, Mr. Hodson, C.E., states * that when investigating "an area of lower greensand, which the Ordnance Survey showed as occupying an area of about $8\frac{3}{4}$ square miles, of which the outflow lay to the south-west, a careful examination proved that a main anticlinal existed which brought up an underground ridge of impervious Weald clay, which, although not apparent on the surface, effectively divided the underground sheet of water, and diverted to an outflow on the south-east the water absorbed on $3\frac{1}{4}$ miles of the watershed, leaving only $5\frac{1}{2}$ miles as possibly available. In addition to this the evidence afforded by the springs conclusively showed that other smaller anticlinals existed, which held up the water as in a series of troughs, which made it very doubtful whether more than one square mile could be commanded by any particular well; whilst to complete the uncertainty, notwithstanding the most persistent efforts, it was impossible to discover all the lower greensand area given by the map, and a large district clearly marked as upper greensand was just as clearly gault."

4. The selection of a site for the well.—Underground water not flowing in a well-defined channel, there are no laws conferring prescriptive rights of property;

* A paper on Underground Water Supplies, communicated to the Incorporated Association of Municipal Engineers, May, 1893.

hence if a well be so placed that its supply of water is affected by the pumping from another well, there is no remedy at law. A site, therefore, should be chosen so as to tap the water at a point where it is least likely to be influenced by other wells (*vide* page 76). The multiplication of deep wells in and around London has lowered the water-level considerably, and in many parts of Essex, wells which were sunk fifty years ago, and then overflowed, only yield water when raised by pumps. In many instances, where the wells had ceased to yield, the deepening of the reservoir (or sunk portion of the well) or the lengthening of the pump pipe has restored the supply.

The advantages of underground water supplies wherever obtainable, as compared with impounding schemes, are that large reservoirs are not required, very little land is wanted, no compensation water has to be provided, or water rights acquired from neighbouring landowners, filter beds are unnecessary, and the possibility of the water becoming polluted is much less. Against these advantages must be placed the cost of pumping; but "in these days of modern high-class pumping machinery," Mr. Hodson says, "the additional cost is so trifling as not to be worthy of serious consideration; in fact, the expenses of pumping to a moderate height with good machinery are even less than the annual charges for interest and working expenses of filter beds alone." These remarks, of course, apply only to comparatively large centres of population. The expense of boring a well to any considerable depth prevents such supplies being obtained for single houses or small communities, except in certain districts where no other source is available. The mode of construction, cost, etc., will be discussed in the section on "Wells and Well Sinking."

The distance within which one deep well can affect another in a continuous stratum depends upon many

circumstances, such as the porosity of the rock, presence of fissures and their direction, etc. In London there are wells within very few yards of each other, the supplies from which appear to be unaffected by their contiguity. On the other hand the Windsor Well, 210 feet deep, belonging to the Liverpool Corporation, is said to have affected the surrounding wells to a maximum distance of 1¾ miles. Certain very deep wells in Essex are found to affect others within a radius of 1½ miles.

In the Lea valley the underground water-level has been carefully ascertained. From Chadwell springs to Cheshunt there is a fall of four feet per mile; from Cheshunt to Waltham Abbey 18 feet per mile, and from Cheshunt to Hoe Lane 11 feet per mile. Between Hoe Lane and Walthamstow the fall averages 9 feet, whilst between here and the city the fall varies from 22 to 32 feet per mile. The increased fall south of Cheshunt is doubtless due to the pumping under London, which is abstracting more water in a given time than can pass through the chalk, compressed as it is by great thickness of clay above it. The effect, therefore, of the excessive abstraction of water from the deep wells in London is affecting the water-level, or plain of saturation, to a distance of 10 or 12 miles north of the city.

The following well sections, typical of those in and around London, are taken from Whitaker's *Geology of London*:—

	Bank of England.		Cold Bath Fields.		Covent Garden Market.	
	Thickness.	Depth.	Thickness.	Depth.	Thickness.	Depth.
River Gravel and made ground . . .	26	26	24	24	25	25
London Clay . . .	111	137	45	69	135	160
Woolwich and Reading Beds	58½	195½	55	124	100	260
Thanet Sand . . .	39	234½	8	132		
Chalk	100	334½	20	152	98	358

	Southend Water-works, Essex.		Waltham Cross, Herts.		Streatham Common, Surrey.	
	Thickness.	Depth.	Thickness.	Depth.	Thickness.	Depth.
Surface Soil	3	3 (Gravel)	13½	13½ (Mould)	2	2
London Clay	414	417	64½	78	178	180
Sands . .	181	598	64	142	195	285
Chalk . .	302	900	..	142 +	...	285 +

The average depth of tube wells in London is about 400 feet, and in most instances the deep-well pump has to be fixed from 200 to 300 feet from the surface. Messrs. Isler and Company, who have bored many of these wells, state that the yield obtained varies from 1,800 to 7,200 gallons per hour from single bores. No attempt appears to have been made to sink a well of any considerable diameter into the chalk under London. Doubtless such a well, with adits, would yield water in much larger quantities than the bores now made. There are great engineering difficulties, however, in sinking through the sands lying between the clay and the chalk, and driving adits at such a depth would be no simple task. The East London Water Company, however, have sunk such a well at Barking, where the chalk is not nearly so deep, and are obtaining some 2,000,000 gallons of water per day therefrom. I am informed that the pumping was at the rate of 5 million gallons per day, when driving the adits, in order to keep down the water to the necessary level.

At Bourn, in Lincolnshire, Messrs. Isler and Company recently bored a well for the supply of the town of Spalding. At a depth of 134 feet in the limestone beds of the lower oolite water was reached, and rushed out of the bore pipe above the surface at the rate of over 200,000 gallons per hour, or about 5,000,000 gallons per day. It is probably the most prolific underground spring yet tapped in England (Fig. 9).

From time to time proposals have been made to further increase the supply of deep-well water for the City of

FIG. 9.—Overflow from an Artesian well recently bored at Bourn, Lincolnshire, by Messrs. C. Isler and Company, for the supply of the town of Spalding.

London, and the whole subject has recently been fully investigated and reported upon by a Royal Commission.

It is calculated that 40,000,000 gallons a day is obtainable from wells in the Lea valley, or 27,500,000 more than is at present being pumped; from wells in the Kent Company's district 27,500,000 gallons, or 11,000,000 a day more than at present. The data and reasoning upon which such estimates are based may be illustrated from that portion of the Commissioners' Report referring to the Lea valley.

1. The area of the collecting surface is estimated at 422 square miles, a portion consisting of bare chalk, or chalk covered with permeables, the remainder of chalk covered with partially or wholly impermeable beds draining on to the chalk.

2. The mean annual rainfall of a long term over this area is 26.5 inches, the average of three consecutive dry years is 22.8 inches, and the fall in the driest year 19 inches.

3. In the Thames valley the average annual evaporation is 16 inches, and in the driest year 14. Assuming the same to hold in the Lea watershed, the evaporation on an average of three consecutive dry years would be about 14.8 inches, leaving 8 inches to run off into the rivers or to percolate into the ground. Of that which gets into the ground a portion is returned to the river. From measurements made as to the yearly discharge at Field's Weir, above which the river receives the whole of the drainage of this area, the mean discharge represents 4.6 inches flowing off. Deducting this from 8 inches, the amount left to percolate is 3.4 inches, which would yield, from an area of 422 square miles, 3,304,000,000 cubic feet per annum, or 56,000,000 gallons per day. But the whole of this water as it travels past the wells down the valley cannot be intercepted.

"In the driest of three years, therefore, especially if it came to the last in the cycle, 56,000,000 would clearly not be obtainable, probably not more than 47,000,000, but we believe that the Companies, after providing reasonably for

all below them, might, under the worst conditions, reckon on obtaining 40,000,000 gallons a day."

Professor Boyd Dawkins believes that the body of the chalk contains such a store of water that it would equalise the rainfall, so that the amount available even during three consecutive dry years would be little short of that obtainable with an average rainfall. With this opinion the reporters disagree, since they consider that the only available water is in the fissures and crevices of the chalk, and that when these are drained the water held in the body of the chalk by capillarity oozes out so slowly as to be practically useless.

In the subjoined table are given the analyses of a number of public water supplies derived from deep wells in various strata. With one or two exceptions they are quite recent. Deep-well water differs little from spring water from the same geological source. An exception, however, occurs in certain districts where the chalk lies at a great depth beneath the London clay, and yields a very soft water containing carbonate and chloride of sodium. This is well adapted for domestic purposes, but not for use in high pressure boilers, nor for irrigation. Boilers in which it is used quickly leak, and the saline constituents have a prejudicial effect upon many forms of plant life.

The utilisation of subterranean water obtained from bored wells is in many of our colonies converting deserts into fruit gardens, and rendering habitable large extents of country in which life was previously impossible on account of the scarcity of water (*vide* Chap. XVIII.).

TABLE VI.

Recent Analyses of Deep-Well Waters.

Town.	Depth of Well.	Geological Formation.	Physical Character.	In Grains per Gallon. Total Solids.	Chlorine.	Nitric Nitrogen.	Temporary Hardness.	Total Hardness.	In Parts per Million. Free Ammonia.	Organic Ammonia.	Nitrites.	Oxygen used.	
	Feet.												
Southport	...	N. R. Sand-stone	Clear and colour-less	27·0	2·1	·0	18·0	18·5	·00	·00	·0	·00	Dr. Thresh.
Pontefract	220	,,	,,	16·0	1·2	·19	8·5	8·5	·00	·00	·0	·25	,,
Leamington	190	,,	,,	29·7	1·4	·04	29·0	23·0	·03	...	...	·26	Dr. Tidy.
Wolverhampton	...	,,	,,	19·0	1·5	·05	5·2	11·7	·00	·00	·0	·04	E. W. Jones, F.I.C.
Birkenhead :													
Spring Hill	399	,,	,,	16·6	2·8	·23	...	9·5	·00	...	...	...	Dr. C. Brown.
Flaybrick Hill	527	,,	,,	13·0	3·2	·22	...	7·0	·00	...	...	...	,,
Borough Road	...	,,	,,	16·4	2·6	·18	...	9·5	·03	...	...	...	,,
Coventry :													
Whitley	200	,,	,,	26·0	1·4	·47	18·0	24·5	·04	...	...	·0	Dr. Tidy.
Spon-end	426	,,	,,	34·0	1·9	·40	15·0	23·6	·03	...	...	·0	,,
Hanley (Hatton)	...	,,	,,	16·2	1·2	·54	2·3	6·1	·00	...	...	·0	,,

Long Eaton Melbourne and Castle Donington	300	Lower Mill-stone Grit	,,	25·3	1·5	·41	9·0	18·0	·00	...	...	·0	Dr. Tidy.
Brighton: Goldstone	160	Chalk	,,	19·3	2·0	·35	8·5	13·5	·0	...	...	...	Dr. Wynter Blyth.
Lewes Road	100	,,	,,	22·6	2·1	·31	10·3	15·6	0·	...	...	...	,,
Canterbury	328	,,	,,	24·0	1·3	·38	16·0	18·6	·01	·01	...	·18	S. Harvey.
Chatham	...	,,	,,	23·5	1·8	·48	17·0	17·5	·04	·02	·0	·08	Dr. Thresh.
Worthing	45	,,	,,	23·8	2·6	·37	13·5	19·0	·00	·02	...	·02	Dr. Dupré.
Norwich	340	,,	,,	37·0	2·8	·80	15·2	22·0	·27	·03	·0	·47	Dr. Thresh.
Sudbury	200	,,	,,	37·0	3·4	·30	21·7	20·0	·00	·02	·0	·07	,,
Saffron Walden	50	,,	,,	46·0	2·6	·95	19·0	23·0	·03	·03	·0	·27	,,
Colchester	218	Chalk under London Clay	,,	83·0	24·8	·03	5·0	5·0	·40	·01	trace	·71	,,
Do. (Donyland)	305	,,	,,	81·5	27·1	·00	8·5	8·5	·94	·015	·0	·125	,,
Halstead	320	,,	,,	36·0	7·0	·00	19·0	20·4	·12	·00	·0	·28	,,
Southend Co. Eastwood, Prittlewell, Southend	685, 866, 900	...	,,	69·0	22·7	·07	2·0	2·0	·01	·04	·0	·75	,,
Harwich, Mistley, etc.	400	,,	,,	55·0	16·4	·05	14·0	14·0	·01	·02	·0	·29	,,
Cold Norton	392	Tertiary Sands	,,	81·0	22·9	·07	2·0	2·0	·01	·02	·0	·52	,,
Steeple	250	,,	,,	98·0	35·0	·25	6·5	6·5	·60	·12	trace	1·26	,, (impure)
Heybridge	126	,,	,,	100·0	36·5	·06	6 5	6·5	·60	·01	·0	1·0	,,
Maldon	234	,,	,,	87·0	24·8	·07	4·0	4·0	·36	·02	·0	·89	...

CHAPTER VII.

RIVER WATER.

THE whole surface of any given country can be divided into "catchment basins," each such basin including an area of land surface draining into a particular river. The district so drained is also called the watershed of the river, and it may vary in extent from a few square miles to thousands of square miles. The watershed of any large river flowing directly into the ocean may be said to include and be greater than the watersheds, drainage areas, or catchment basins of all its tributaries. The actual point at which a river takes its rise is often difficult to decide. If it originates at the natural outlet of a lake or from a powerful spring, the point at which it comes into existence is obvious. If, however, it is formed by the meeting of the waters of two or more rivulets of tolerably equal length and flow, then the claims of any one of the streams to be the parent stream may be disputed. A stream may arise from a spring, and for some short distance may consist of pure spring water, but its volume is soon increased by surface and subsoil water, so that all river waters may be said to consist of mixtures of waters in varying proportion from all three sources. As these waters will also vary with the geological character of the district, and the nature of the subsoil and surface, it is obvious that the waters of different rivers will not only differ from each other, but that water from the same river taken at different points, or even from the same point at different seasons, may vary considerably

in composition. Where the water of a tributary differs much in appearance from that of the parent stream, the difference can often be observed for some distance below the point of entrance of the smaller stream. In some instances the effect of such admixture is very marked. Upon Axe Edge in Derbyshire a highly calcareous stream joins a ferruginous one. Before combining, both are clear; after mixing, the stream becomes red and turbid, deposits an ochrey substance upon its bed, and only again becomes pellucid after flowing a considerable distance.

Unfortunately, in all inhabited districts the rivers not only receive the natural drainage, but are also the ultimate receptacles of all the polluted waters (sewage) artificially collected from manufactories, groups of houses, and from towns within their watersheds. Notwithstanding the Rivers Pollution Act, nearly every stream of any size in this country is at the present time so befouled; the defilement in many instances being so great that the rivers are practically open sewers. Where the sewage is chemically treated before being allowed to pass into the streams, most of the suspended impurities are removed, and possibly a portion of those previously held in solution. If the sewage be disposed of by broad irrigation or by intermittent downward filtration through land, it is still further purified, most if not all the organic matters being removed or destroyed by oxidation. From highly cultivated land also a certain amount of filth may reach the streams, especially during heavy rains, when much of the rainfall not only dissolves impurities but carries with it into the river other matters in suspension. This rapid inrush of water disturbs the mud and deposit at the sides and in the bed of the stream, and for a time increases the rapidity of the flow, and renders the water turbid and still more impure. Rivers rising and flowing through very thinly-populated districts may yield water to which no possible objection can be taken, from a hygienic point of view,—water which

may be admirably adapted for all domestic and other purposes, and which it is in the highest degree improbable will ever act as the carrier of the germs of disease. Many rivers, however, are utilised as sources of public water supplies which are continuously receiving sewage from towns or villages at points above the intake. The Thames is such a river, and the Royal Commission which recently inquired into the water supply of the Metropolis reported that there was no evidence of the pollution causing any injury to the health of those drinking the water, and even advocated the increased utilisation of the Thames for the supply of water to the capital. The utilisation of rivers as water supplies is so dependent upon the possibility of the water being purified, that, although the subject will be discussed later, some reference must be made to it here. The self-purification of rivers is by one set of observers regarded as an indisputable fact, whilst by others it is regarded as a myth. The Royal Commission on Water Supplies in 1869 reported that when sewage was diluted in a stream with not less than twenty times its volume of water, that the polluting matter was completely oxidised and destroyed during a flow of "a dozen miles or so." The Rivers Pollution Commissioners in 1874 reported that, as there was no proof of this, they had undertaken a series of observations and experiments and had arrived at a diametrically opposite conclusion. After describing the experiments, etc., they conclude that "whether we examine the organic pollution of a river at different points of its flow, or the rate of disappearance of the organic matter of sewage or urine when these polluting liquids are mixed with fresh water and violently agitated in contact with air, or finally, the rate at which dissolved oxygen disappears in water polluted with 5 per cent. of sewage, we are led in each case to the inevitable conclusion that the oxidation of the organic matter in sewage proceeds with extreme slowness, even when the sewage is mixed with a large volume of unpolluted

water, and that it is impossible to say how far such water must flow before the sewage matter becomes thoroughly oxidised. It will be safe to infer, however, from the above results that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation." In the same Report is quoted the opinion of Sir Benjamin Brodie, F.R.S., "that it is simply impossible that the oxidising power acting on sewage running in mixture with water over a distance of any length is sufficient to remove its noxious quality." This Royal Report notwithstanding, it is an undoubted fact that in many rivers a purifying action is taking place, and with great rapidity. Thus the river Seine, after becoming horribly polluted as it runs through Paris, gradually improves in appearance, and about 30 miles below the city is actually found upon analysis to be purer than it was before it received the sewage of the city. The water of the Thames at Hampton Court contains no more organic matter than it does at points higher up, before it has received the sewage of the towns along its course. The Royal Commission on Metropolitan Water Supply, after hearing much evidence, concluded that, "After all, the main evidence on which we have to base our judgment is that furnished by London itself. For more than thirty years the inhabitants of London have been drinking water taken from the Lea and the Thames above Teddington, at points either the same as those at which the present intakes are situated or at points where the chances of contamination were greater, and the population that has been thus supplied has varied from some two and a half to five millions. Here, then, we have an experiment on a gigantic scale, largely exceeding in compass the aggregate experience of all the other places in which outbreaks of fever have been subject to inquiry, and an experiment made, moreover, under the very conditions, or at any rate under no more favourable conditions than those that are still in operation in London. What has been the

practical issue of this prolonged and wide experience? Every medical witness that has appeared before us, whether his general feeling was favourable or unfavourable to the water, has told us unhesitatingly that he knows of no single instance in which the consumption of this water has caused disease. This is the unanimous testimony of the medical officers of health, of the water analysts, and of the bacteriological experts, — of all, in short, whose attention has of necessity been directed to the subject." The Commissioners therefore think that the risk of disseminating disease, even by admittedly polluted river water, is, under conditions similar to those which obtain in the Lea and the Thames, and where the water is equally carefully collected and filtered, so small as to be negligible.

The serious outbreaks of typhoid fever in the Tees valley in 1890-91, which were investigated by Dr. Barry, a Local Government Board inspector of great experience, were attributed by him to the pollution of the river Tees by sewage. The Medical Officer to the Local Government Board, in his introduction to this Report, says, "Seldom, if ever, has the fouling of water intended for human consumption, so gross or so persistently maintained, come within the cognisance of the medical department, and seldom, if ever, has the proof of the relation of the use of water so befouled to wholesale occurrence of enteric fever been more obvious and patent." These outbreaks were carefully considered by the Metropolitan Commissioners, and they concluded that Dr. Barry's evidence connecting them with the polluted Tees water was not conclusive.

Amidst such a conflict of opinion it is safest to suspend one's judgment; but even the most ardent advocate of the use of river water will admit that it should receive as little sewage as possible, and that the sewage should be previously subjected to the most effective system of purification. Storage reservoirs also should be provided, sufficiently large to allow of the average daily supply being furnished without

taking in any part of the flood-water, and the filters should be kept in a thoroughly efficient condition. That the neglect to maintain these conditions might result in an outbreak of typhoid fever or cholera seems possible if not even probable, and the fact that a town using polluted water has remained free from such epidemics for a series of years is no proof that such immunity will be perpetual. In the section treating of "Diseases disseminated by Potable Waters" many examples will be quoted in which polluted river water has been proved, so far as actual proof is possible, to have been the cause of serious outbreaks of both typhoid fever and cholera.

The amount of water which can be taken from a river for supplying a town varies according to (*a*) the area of the watershed, (*b*) the topography and geological character of the ground, (*c*) the average rainfall, and the rainfall during a consecutive series of dry years, (*d*) the distribution of the rainfall throughout the year, (*e*) the amount of water which must be supplied for "compensation" purposes, and (*f*) the facilities for obtaining storage.

The available watershed, of course, includes only that portion of the whole watershed which feeds the river above the point at which the water will be abstracted. This can only be ascertained by actual measurement, though approximate estimates may be made from hydrographical maps on which the river basins are defined.

The contour of the ground surface also affects the supply, for upon this depends greatly the rapidity with which the rainfall, especially when heavy, will flow over the surface into the stream. The character of the surface and of the subsoil will also affect the amount which will flow directly into the river, and the amount which will percolate and pass into the river at a lower level. All the above also will be factors in determining the amount of evaporation, or, in other words, of determining the available rainfall. The surface drainage area does not always correspond with the

true drainage area, since there may be springs within the surface area fed from a source without that area; and, on the other hand, rain which falls on the surface area may pass by underground channels beyond the limits of the watershed. All these possibilities have to be borne in mind, and the locality carefully examined to ascertain whether such conditions exist, and to what extent they will affect the water supply.

The way in which the rainfall in any particular district can be ascertained has already been described. The minimum rainfall for a year, or a series of years, can only be determined from records continuously taken for many years; but it is found that, under ordinary circumstances, the maximum rainfall exceeds the average by one-third, whilst the minimum falls short of the average by the same amount. The mean rainfall during the three driest consecutive years is usually about one-fifth less than the average. Thus, where the average rainfall for a series of years is 30 inches per annum, the maximum will be about 40 inches, the minimum 20 inches, and the mean for the three driest consecutive years 24 inches. Where careful daily gaugings of a stream have been made for a few years, the proportion of the rainfall finding its way into it can be ascertained, and by calculation the amount which would pass into the river, with the minimum rainfall, can be approximately determined. The following table, compiled from the *22nd Annual Report of the State Board of Health of Massachusetts*, shows the rainfall received and collected during a series of years on the Sudbury River watershed.

During the sixteen years, 1875-90 inclusive, the average rainfall was 45.8 inches. The calculated maximum rainfall on this area is 61.1 inches, and the minimum 30.5 inches. The observed maximum and minimum were 57.9 and 32.8 inches respectively. The mean rainfall for the three driest years (1882-84) was 38.8, whilst the calculated mean is 36.6 inches, so that doubtless the calculated amounts will closely

approximate to the truth when the records for a much longer period of years are available. The percentage of rainfall collected does not vary directly with the rainfall, and neither the smallest nor largest proportion collected corresponded with the lowest and highest rainfalls; but the results do not vary to such an extent as to render it difficult to determine approximately the minimum amount available. The cause of this variation is due in part to the seasonal variation in the rainfall, and in part to the variation in the amount evaporated.

Year.	Rainfall.	Rainfall Collected.	Per Cent. Collected.
1875	45·49	20·42	44·9
1876	49·56	23·91	48·2
1877	44·02	25·49	57·9
1878	37·93	30·49	52·6
1879	41·42	18·77	45·3
1880	38·18	12·18	31·9
1881	44·17	20·56	46·6
1882	39·39	18·10	45·9
1883	32·78	11·19	34·1
1884	47·13	23·78	30·5
1885	43·54	18·92	43·4
1886	46·06	22·82	49·5
1887	42·70	24·23	56·7
1888	57·46	35·75	62·2
1889	49·95	29·06	58·2
1890	53·00	27·00	50·9
Mean for 16 yrs.	45·80	22·67	49·5

A knowledge of the seasonal rainfall and the seasonal variation in the flow of the stream is also absolutely necessary, since upon these factors depend in a great measure the amount of storage which will be required to collect the water during periods of abundance for use during periods of drought. During the sixteen years' records of the Sudbury River, the mean daily flow during the month when the river was lowest was only 60 gallons per acre of the watershed; during the driest three months it was 148

gallons; during the driest twelve months, 777 gallons; whilst the mean daily flow for the whole period was 1,686 gallons. From these records the reporters to the Massachusetts State Board of Health have calculated a table showing the "amount of storage necessary to make available different quantities of water per day from each square mile of watershed, where the conditions are similar to those which exist at Sudbury River." To obtain 100,000 gallons per day per square mile, the storage reservoir must be capable of holding 2,200,000 gallons per square mile of watershed; to obtain 1,000,000 gallons per day, the reservoir must hold 540,000,000 gallons. For intermediate quantities the original table must be consulted.* Of course these results can only be used where the conditions which obtain resemble somewhat those of the watershed under consideration. The following table for the river Thames is calculated from data given in the *Report of the Royal Commission on Metropolitan Water Supply*:—

Year.	Rainfall.	Rainfall Collected.	Per Cent. Collected
1883	28·4	13·3	46·8
1884	22·9	7·0	30·8
1885	29·15	8·3	28·5
1886	31·1	11·1	35·7
1887	21·3	8·2	38·5
1888	28·45	8·9	31·3
1889	25·6	9·1	35·5
1890	22·8	5·7	25·0
1891	33·3	9·8	29·3
Average of 9 yrs.	27·0	9·05	33·5

If this table be compared with the corresponding one for the Sudbury River, it is evident that a considerably larger proportion of the rainfall is available from the watershed of the Sudbury than from that of the Thames.

* *State Report*, 1890, p. 342.

Mr. Beardmore calculates that during summer, the Thames, Severn, Loddon, Medway, and Nene, which flow over a variety of geological strata, only carry off less than one-eighth of the rainfall, whilst the Mimram and Wandle, which arise in and flow through chalk districts only, yield nearly half the total rainfall. Certain rivers are much more constant in their flow than others, the result depending chiefly upon the conformation of the watershed and the character of the subsoil. If the stream be fed chiefly with surface water the variation will be very considerable, whilst if fed chiefly from the subsoil the flow will be comparatively uniform. All these factors, therefore, have to be taken into consideration when estimating the available supply and the amount of storage necessary.

Where there are riparian owners having a right to the use of the water for any purpose, as for manufacturing, or as a motive power, further complications are introduced. Sufficient water must be allowed to pass down the river to satisfy all their reasonable requirements. Only the amount in excess of this can be appropriated, and as during seasons of drought they may require the whole flow of the river, the impounding reservoirs must be large enough to store water during seasons of abundance sufficient to tide over these periods when none can be collected.

The quantity of water which must be stored to equalise the supply during the longest period of drought which may possibly occur can only be determined when the average daily demand is approximately known, and the whole of the conditions above referred to have been carefully investigated. The number of days' storage required varies in this country from 120 to 300; the smaller quantity only being required on the western side, where the rainfall is heavy and the number of rainy days considerably above the average. In the eastern counties, where exactly the opposite conditions obtain, about ten months' storage may be necessary.

The amount of storage required may be calculated from the rainfall statistics only, or from the stream gaugings, but both must be considered if the result is to be reliable. The gaugings may be effected by various methods: (*a*) by means of sluices; (*b*) by aid of current meters; (*c*) by means weirs; (*d*) by gauging the surface velocity. Where a rough approximation only is desired a straight portion of the stream may be selected which is tolerably uniform in width and section, and where the water flows smoothly, or where by a little labour such uniformity may be produced. By plumbing the depth at different points across the stream and measuring the width, the cross section can easily be calculated. The length of the selected portion, 20 yards or more, must be marked off, and the time noted which it takes a chip or float to traverse this length in mid-stream on a calm day. The mean velocity of the whole body of the water may be taken as .75 that of the surface velocity. These data are sufficient to give the volume required.

For example, the area of a section of a stream is found to be 45 square feet, and the time taken by a float in traversing a distance of 60 feet is 80 seconds. Required the flow in gallons per day.

$$\frac{45 \times 60 \times \cdot 75}{80} = 25\cdot 3125 = \text{flow in cubic feet per second.}$$

$$25\cdot 3125 \times 60 \times 60 \times 24 \times 6\cdot 25 = 13{,}668{,}750 \text{ gallons per 24 hours.}$$

The ratio of the mean to the surface velocity is not a constant, and its value is variously estimated by engineers from the results of actual experiments. It varies with the rapidity of flow, the nature of the channel, depth of water, or form of cross section, but the first named is probably by far the most important factor. Mr. Beardmore adopts the formula $U = V + 2\cdot 5 - \sqrt{5V}$ where U equals the mean, and V the surface velocity per minute. This formula gives the following values for U:—

Surface Velocity in Feet per Minute.	Mean Velocity.	Value of U in terms of V.
5	2·5	·5
10	5·5	·55
20	12·5	·625
50	36·5	·73
100	80·2	·802
200	170·9	·885

Where greater accuracy is required and the stream is large, a current meter may be employed.

"Having fixed on the station where the cross section of a large river is to be taken and the velocities ascertained, take a number of soundings across the stream, at 8, 10, or 12 points, according to the breadth. These lines of sounding

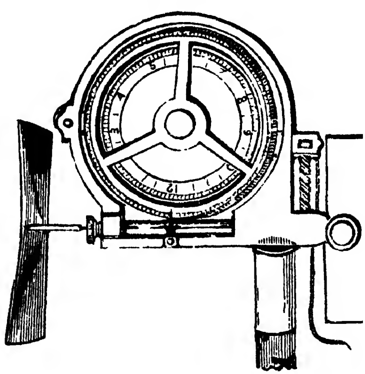

FIG. 10.

divide the section into a number of trapezia, and the area of each of these is to be calculated. Then, at a point half-way between each of the two lines of sounding, is to be fixed a small boat containing the current meter (Fig. 10), by means of which 5, 6, or 7 velocities are to be determined in the same vertical line. The arithmetical mean of these

is then to be multiplied by the area of the trapezium to which they apply. The sum of these products is evidently the discharge of the river — it is equivalent to the total sectional area multiplied by the mean velocity" (Hughes's "Waterworks," quoted from D'Aubuisson's *Traité d'Hydraulique à l'usage des Ingénieurs*).

In artificially constructed channels of uniform cross section, such as canals, culverts, and pipes (the two latter may be running full, but must not be under pressure), various formulæ have been devised for estimating the flow from the fall per mile and the hydraulic mean depth.* Beardmore's modification of Eytelwein's formula is the one usually employed—

$$U = 55\sqrt{2RH},$$

where U equals the mean velocity in feet per minute, R the hydraulic mean depth, and H the fall in feet per mile.

Example.—In a circular channel of 2.5 feet diameter, having a fall of five feet per mile, and running exactly half full of water, what is the flow in cubic feet per minute?

$$R = \tfrac{5}{8}\,.\ H = 5\,.\ U = 55\sqrt{2 \times 5 \times \tfrac{5}{8}} = 137{\cdot}5.$$

The area of a section of the water is $\dfrac{2{\cdot}5^2 \times {\cdot}785}{2} = 2.453$ feet.

This, multiplied by the velocity, 137.5, gives a yield of 337.3 cubic feet per minute.

Streams of any magnitude are usually gauged by engineers by the aid of artificially constructed weirs. Theoretically the velocity with which the water passes over the weir is that which a body would acquire in falling

* The hydraulic mean depth is the sectional area of the water divided by the wetted perimeter. In circular pipes running full, $3{\cdot}14d$ equals the wetted perimeter, and $d^2{\cdot}785$ the cross section of the water; R therefore equals $\tfrac{1}{4}d$.

through a distance equal to the difference between the surface level of the water above the weir and the surface of the weir itself. A body falling from rest acquires at the end of one second a velocity, g, which is approximately 32 feet per second. The mean velocity at the end of any number of seconds, t, will be $\frac{o+tg}{2} = \frac{tg}{2}$, the space traversed, s, in that time will be $\frac{t^2g}{2}$, and the velocity at the end of that period tg. Eliminating t, we find that $v^2 = 2sg = 2 \times 32 \times s$, therefore

$$v = 8\sqrt{s}.$$

Theoretically, therefore, the velocity with which water passes over the actual surface of the weir is eight times the square root of the difference in level above referred to. But this is the lowermost stratum of the water only, the strata above having a less velocity, decreasing upwards as the square root of the depth from the surface level. The mean velocity of all the strata will be that of the particles at $\frac{2}{3}$ the depth of the lowermost, therefore

$$v = \tfrac{2}{3}8\sqrt{s} = 5\tfrac{1}{3}\sqrt{s}.$$

Unfortunately friction has to be taken into account, and as this varies with the shape of the weir, its width, etc., the above formula has little more than theoretical interest. Numberless experiments have been recorded and many formulæ deduced therefrom for weirs of different kinds. Here, however, it is only necessary to refer to the one most frequently employed, that derived from Mr. Blackwell's experiment made on the Kennet and Avon Canal on the flow of water over 2-inch planks. Let Q equal the quantity of water flowing over the weir in cubic feet per minute, then

$$Q = cw\sqrt{s^3}.$$

Where w = the width in feet, s the depth of water in inches, and c = a constant multiplier, found by experiment and given in the following table (quoted from Slaggs' '*Water Engineering*):—

Depth s = 1 inch	Value of c = 3·50
„ = 2 inches	„ = 4·25
„ = 3 „	„ = 4·44
„ = 4 „	„ = 4·44
„ = 5 „	„ = 4·62
„ = 6 „	„ = 4·57
„ = 7 „	„ = 4·61
„ = 8 „	„ = 4·48
„ = 9 „	„ = 4·44

For depths of 3 inches and upwards c may evidently be taken as 4.5. As an example, it is required to calculate the flow over a weir of 5 feet in width, the level of which is 6 inches below the even surface of the water.

Since $s = 6$, $c = 4{\cdot}5$ and $w = 5$

$$Q = 4{\cdot}5 \times 5 \times \sqrt{6^3}$$

$$Q = 333 \text{ cubic feet per minute.}$$

Under certain circumstances, as where a lock gate and sluice are available, the flow may be determined from the area of the sluice and the vertical distance between the centre of the sluice and the level of the water in the stream. Theoretically the velocity of the water passing through the sluice would be $8\sqrt{s}$, but from friction and other causes it is always less than this. With very small sluices of from 1 to 16 square inches area, Poncelet and Lesbros' factor, .62 may be taken as approximately correct. If therefore the area of the sluice A be known, the flow per second will be:—

$$Q = A \times {\cdot}62 \times 8\sqrt{s} = \text{approximately } 5\,A\sqrt{s}.$$

If A and s be expressed in feet, Q will be the flow in cubic feet per second.

Where the river is of considerable dimensions, and it is desired to record the variations in the flow automatically, a tide-gauge may be used (Fig. 11).

By aid of such an instrument the rise and fall of the float is recorded on a revolving cylinder, so that not only the extent of the variations, but the exact time at which they occurred is registered.

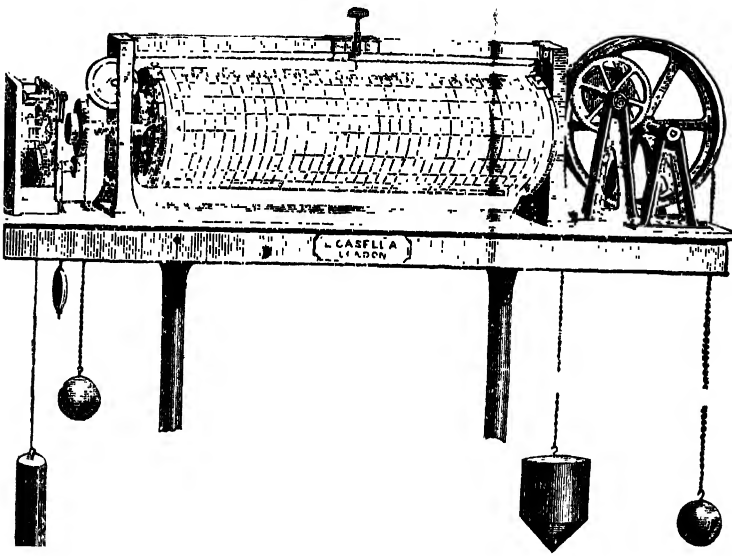

Fig. 11.

Where the amount of water to be abstracted from a river is very small compared with its volume, of course all these elaborate investigations are unnecessary. In such cases also, storage will only be required to supply the town during periods when the river is in flood and the water turbid.

In exceptional cases only can river water be abstracted at a point sufficiently high to supply a town by gravitation.

Usually the water is pumped into storage reservoirs, from which it flows on to the filter beds, and it may again require to be pumped after filtration into service reservoirs at such an elevation as to permit of the water supplying the town by gravitation. Service pipes may be attached * to the rising main if houses have to be supplied *en route*. When pumping is going on the flow will be from the pumping station to the houses, but when the pumping ceases the flow will be in the contrary direction, from the service reservoir. The water taken from the Thames and Lea for the supply of the metropolis is all pumped into service reservoirs in order to obtain the necessary pressure, the height to which it is lifted being on an average 200 feet.

Limited supplies of water can be obtained from streams having a good fall, by aid of rams, turbines, or water-wheels, when the place to be supplied is at too great an elevation to be directly supplied by gravitation. These automatic pumping machines will be described in a later section.

A large number of towns in England derive their water supplies from rivers. In the Tees valley, Darlington, Stockton, Middlesborough, and several smaller towns are supplied from the Tees; Durham is supplied from the Wear, Carlisle from the Eden, Ripon from the Ure, York from the Ouse, Knaresborough from the Nidd, Leeds from the Wharfe and Washburn, Doncaster from the Don, Wakefield in part from the Calder, Ely from the Ouse, Leamington from the Leam, Shrewsbury, Worcester, and Tewkesbury from the Severn (Cheltenham also occasionally), Plymouth from the Mew, Sandown (Isle of Wight) from the Yare, etc. On account of the prevalence of typhoid fever in certain of these towns (Stockton, Darlington, Middlesborough, York, and Newark, for example) the possibility of obtaining water supplies from other sources has been considered. On the other

* There are objections to this procedure.

hand, certain towns are contemplating improving their present supplies by resorting to rivers. Cheltenham, for example, is completing works for augmenting its present supply by drawing from the Severn at Tewkesbury. It is now supplied in part by spring water collected in brick-built reservoirs (this water when stored has a tendency at certain seasons of the year to acquire a disagreeable odour from the growth of Chara and numerous minor vegetable organisms), and in part by the head waters of the Chelt, which is also impounded in a reservoir. This reservoir will hold 100,000,000 gallons, or about 100 days' supply for the town, and is usually full to overflowing about the end of March; it then loses water pretty continuously until November, when again the feeders exceed the draught. 100,000 gallons a day have to be turned down the Chelt as compensation water. This water is subject at certain seasons to acquire a red tint from a growth in it of Crenothrix. The closing of surface wells, and the increasing demand for water for water-closets and for flushing sewers, and other municipal purposes, has on several occasions run the reservoirs so low as to cause considerable anxiety. There is within five or six miles of the town a perennial supply of pure water from springs, which form the head waters of the Thames, but Parliament has refused to allow them to be diverted for the use of the town. In 1881 powers were obtained for bringing water from the Severn at Tewkesbury, and for supplying that town and the villages *en route*. The recent dry seasons and the increased requirements of the town have impelled the Cheltenham Corporation to utilise these powers, and the filter beds existing at Tewkesbury having been largely augmented, a water main has been laid from Tewkesbury to Cheltenham (9 miles), and powerful pumping engines installed. The Medical Officer of Health says that the water is wonderfully good, and the volume magnificent. That it receives the sewage of several towns along its course is acknowledged,

but that there is any evidence of this pollution at Tewkesbury is denied. Worcester has taken its supply from the Severn for forty years, and although the filtration is said to have been in past time far from perfect, it has suffered nothing. This town, however, pours its sewage into the river at a point seventeen miles above the Cheltenham intake, and a mandamus has been issued to compel the town to purify its sewage. Between Worcester and Tewkesbury very little sewage enters the Severn. With the Worcester sewage diverted or purified, the Medical Officer and engineer consider that the Severn water, properly collected and filtered, will afford an abundant and perfectly wholesome supply to Cheltenham, and more especially as the towns already deriving their water supplies from the Severn have never been unduly affected by typhoid fever. During the last three dry summers the Severn supply has had to be largely resorted to by Cheltenham, and during the periods of its use no increase of typhoid fever cases have occurred. The amount of typhoid, in fact, has never been less in Cheltenham than during these years.

Table VII. (Chapter X.) contains the analyses of several typical samples of river water, including the filtered waters supplied by the various London companies, during August 1892, derived from the rivers Thames and Lea.

CHAPTER VIII.

QUALITY OF DRINKING WATERS.

MUCH has already been said about the suitability of waters from various sources for domestic use, and fortunately it may be taken as being generally true that the best water for drinking purposes is also the best for cooking, washing, and other domestic requirements, and also for probably all manufacturing processes. A high degree of purity is not necessary in the latter case; hence a water which may be totally unfit for drinking may still be of value for many other purposes; but as dual supplies introduce complications, and usually mean additional expenditure, it is an undoubted advantage to have a single supply equally well adapted for all uses. As health, however, is of paramount importance, a pure water supply is an absolute necessity for domestic use, and it is only where the supply is limited, or the water is unfitted in some way (as by being too hard), or is too expensive for manufacturing purposes, that there will be any demand for an additional supply. In many towns the requirements of manufacturers are met by the laying of special mains conveying water from a river, or some other source, yielding water too impure for domestic use, yet perfectly well adapted for their special requirements. Such water may also be utilised for flushing sewers, etc. On the sea-coast sea-water is sometimes used for flushing sewers, etc., especially where it is cheaper to pump it than use the domestic supply, or where the latter is not too abundant.

The characteristics of a good potable water are freedom from colour, odour, taste, turbidity, and excess of saline matter and the total absence of all injurious substances, whether of animal, vegetable, or mineral origin.

Colour.—A hygienically pure water is almost invariably quite colourless when viewed in small bulk, as in a tumbler, though when looked at in a reservoir, or in a tube about 2 feet long, it will have a faint bluish tint.

Professor Tyndall showed that when a powerfully con-

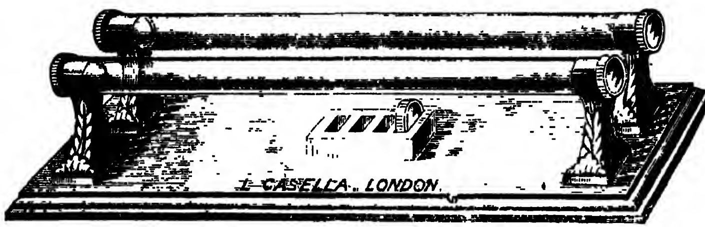

FIG. 12.—Tubes for comparing the colours of potable waters.

densed beam was caused to traverse a sample of water, the amount of light scattered depended upon the quantity of impurity present. But "an amount of impurity so infinitesimal as to be scarcely expressible in numbers, and the individual particles of which are so small as wholly to elude the microscope, may, when examined by the method alluded to, produce not only sensible, but striking, effects upon the eye." Experimenting with sea-water, he found that a blue colour corresponded with a high degree of purity. A yellow-green water in the luminous beam appeared exceedingly thick with very fine particles, and a bright green water, though much more pure than the yellow-green, was far more impure than the blue. A green or yellow tint usually indicates the presence of vegetable or animal matters; a brown tint is almost invariably due to peat; whilst a reddish tint indicates the presence of iron. Surface waters from hills and moorlands often contain

peaty matter in solution and are discoloured thereby, but this discolouration forms only a sentimental objection to the water, unless excessive, and the peat does not appear in any way to affect the health of those who use it. Such waters are usually very soft and well adapted for manufacturing purposes generally, but there are some processes, as the making of the finest qualities of paper, in which the use of peaty water is objectionable. Some bleaching action takes place when such water is freely exposed to sunlight and air, as in lakes and large reservoirs. From observations made in Massachusetts it was found that water "must be stored several months to cause any material reduction in colour, and from six months to a year in order to remove practically all of it." A filter of sand and loam removed the whole of the colour from the water of the Merrimac River for two years. During the third year the filtered water was occasionally coloured; during the fourth and fifth year the effluent from the filter "was very slightly but uniformly coloured." New sand would therefore appear to be a more efficient colour-remover than sand which has been in use as a filtering material for a length of time.

Where the water has a reddish or reddish-brown tint due to the presence of iron, access of air causes it quickly to acquire an opalescent appearance, from the formation of a more highly oxygenated and insoluble compound of iron. This deposits slowly and the water loses its colour. The objectionable character of such water for washing purposes is well known.

Odour.—Absolutely pure water is odourless, and, with rare exceptions, so are all hygienically pure waters. Peaty waters, especially when warmed and shaken in a bottle with air, give off a peculiar and characteristic odour. Waters from certain sources, though quite free from pollution, have an odour of sulphuretted hydrogen (rotten eggs). Where this is strong and persistent the water is classified amongst mineral waters as "sulphuretted." In some parts of Essex

the water derived from veins of sand beneath the boulder clay has a faint but decided odour of this gas; the smell entirely disappears upon leaving the water exposed to the air for a short time in a bucket or tank. In these districts, however, the inhabitants will drink any kind of ditch or pond water rather than this, so convinced are they that such a smell can only proceed from the vilest sources. With these exceptions any water giving off an odour when warmed must be considered impure, and therefore inadmissible as a domestic supply. Odorous waters appear to be much more commonly met with in some districts, and in some seasons, than in others. In Massachusetts, out of 1,404 samples of drinking water examined, from reservoirs, ponds, lakes, rivers and brooks, only 275 were entirely destitute of odour, 458 had a "vegetable or sweetish" odour, 202 a "grassy" odour, 84 a "mouldy" odour, 146 an "aromatic" odour, 47 a "fishy" odour, 92 a "disagreeable" odour, and 100 an "offensive" odour. Mr. G. N. Calkins, who has made a special study of this subject, concludes that there are three classes of odours: (1) odours of chemical or putrefactive decomposition, (2) odours of growth, and (3) odours of physical disintegration—the two latter being probably due to odorous oils. Theoretically, the odours of a water may be due to dissolved or suspended matters of mineral origin, but no such substances are known to affect great bodies of water. Decaying vegetable matter, he thinks, is responsible for the "vegetable and sweetish" odours, and dead animal matter for the "offensive" odours. The "grassy" and "mouldy" odour cannot yet be explained. The "aromatic" and "fishy" odours are more important, since they are prone to develop at certain seasons of the year in waters which at other periods are quite destitute of smell. These are invariably surface waters which have been stored for some time in open reservoirs.

The fishy odour is said to be due to various Infusorians,

one of which, the *Uroglena Americana*, has during the past two or three years infested several of the drinking waters of the State.

Professor Remsen, who investigated the cause of the "cucumber" odour * of the Boston water in 1878, attributed it to the decomposition of a fresh-water sponge (*Spongilla fluviatilis*). Mr. Rafter attributed the disagreeable fishy odour and taste of a water which he examined to the presence of *Volvox globator*, and I have observed a similar coincidence in a public water supply in this country.

From time to time an organism "barely visible to the naked eye," globular in form, greenish yellow in colour, and, on superficial examination, closely resembling *Volvox globator*, has been found in several of the Massachusetts water supplies, and recently it appeared in great abundance in the ponds supplying Norwood and Plymouth. The water in the ponds had no marked odour, but as delivered from the taps in the towns it had a most objectionable smell. This colony-forming infusorian was found to belong to the genus *Uroglena*. Three species are described, but one only, the *Uroglena Americana*, appears to impart an odour to water. When in a state of disintegration it liberates an oil-like substance with an intensely disagreeable smell. As this species has frequently been mistaken for *Volvox*, possibly in cases where bad odours have been attributed to the latter they were really due to the *Uroglena*. Such appears to have been the case at Middleton and Meriden, Connecticut, in 1889. The organism was found in great abundance in the reservoirs, but was absent in the tap water, and the latter alone had any odour. Apparently while traversing the water-mains the delicate structure becomes completely disintegrated, liberating the strongly-smelling oily constituent. *Bursaria gastris* gives a sea-weed

* "Odours in Drinking Waters": *Report of Massachusetts State Board of Health*, 1892.

like odour, *Cryptomonas* furnishes a "candied violet" odour, *Asterionella* and *Tabellaria* (Diatoms) an "aromatic" odour.

Crenothrix, a fungoid growth of thread-like form, can only thrive in water containing protoxide of iron and organic matter, and, by its decomposition, often causes water to acquire a disagreeable odour and taste. The Berlin water supply from wells sunk near the Tegeler Lake had to be abandoned on account of the abundant growth of this organism. Its appearance in the Rotterdam water supply led to the formation of the "Rotterdam Crenothrix Commission," and Prof. Hugo de Vries reported that Crenothrix was not a ground water organism as was generally supposed, but that it was found in many surface waters. As the result of his observations and experiments, he expressed the opinion that two factors are necessary for its growth to become so rapid as to render a water unpalatable. These two factors are—the presence of decomposing organic matter, and the presence of protosalts of iron. For a detailed account of this organism and its relation to water supplies, an exhaustive article by Prof. W. F. Sedgwick, in the *Technological Quarterly*, Boston, 1890, may be consulted. In the Annual Report of the Massachusetts State Board of Health, there is also a mass of information bearing upon this subject; and in *Public Health* for October, 1896, Dr. Garrett describes the effect of this organism on the Cheltenham water supply. This water contains a trace of iron, and in the spring of that year it became "rather red and turbid" and at the same time acquired an unpleasant odour. A little later the whole of the water in a particular reservoir was observed to be affected. In about three months matters returned to their normal condition. The organism which caused this phenomenon Dr. Garrett calls *Crenothrix polyspora (var.) Cheltoniensis*. His paper contains a very full account of this organism, and is well illustrated. Dr. Garrett in the

same paper mentions that the water in the lake at Pittville Park had turned a bluish-green colour and acquired a strong odour. In this water he found a species of *Anabæna* of the *Nostoc* order, and a yellow-green monad. To these he attributes the colour and odour.

In 1898 I was consulted with reference to a large public supply which had become infested with a vegetable growth giving the water a very objectionable appearance and an ammoniacal fishy odour. The growth consisted of an unbranched, multicellular chlorophylous alga corresponding to the *Microsporon vulgaris* of Cooke, but better known as the *Conferva Bombycina* of Kutzing. When this organism dies and breaks up, the odorous products are formed.

Many times during recent years I have been called upon to examine well waters which had suddenly developed an unpleasant appearance and odour. These cases almost invariably occur in the late summer and autumn, and the changes are due to the growth of a Crenothrix.

Waters most usually affected by these growths contain traces of organic matter in solution, and often traces of iron, but it will be noted that certain waters such as those derived from the base of the oolitic escarpment, which are of great organic purity and in every way admirable, when stored in open reservoirs exhibit a great tendency to serious deterioration by the growth of *Chara*, as well as numerous microscopic vegetable organisms—*Volvox*, *Oscillatoria*, etc. —which give the water a disagreeable odour, flavour and appearance. No such growths occur in the same water when stored in covered reservoirs, the presence of light being absolutely necessary for their growth and multiplication.

At Syracuse, N. Y., the water frequently became offensive during the autumn from the growth of vegetable matter in the lake. During the last two years men have been employed to skim off all such growths as they appeared, and the water has not been tainted since.

At Bolton (Lancashire) the water supply in July, 1891, gave rise to some alarm, as it had somewhat suddenly acquired a "fishy" odour and taste. Dr. Adams, the Medical Officer of Health, attributed the disagreeable odour to various forms of fresh-water Algæ, but more especially to *Conferva Bombycina*, since this species when decomposing yields fœtid gases, "the smell of which resembles that of fish not in very fresh condition." He regarded the growth as being fostered by the presence of phosphates derived from manure and sewage on the watershed area. As fishes feed on such vegetable matters, Dr. Adams advised stocking the reservoir with fish, an experiment which has been tried elsewhere, with doubtful results. At Cheltenham, in September, 1891, the water derived from an uncovered reservoir fed by springs was found to have acquired this fishy odour and flavour. These springs supply three reservoirs, A, B, and C. A is covered over, B and C uncovered. The open reservoir, C, was the one in which the water was affected, and it was found when emptied that upon the sides and bottom there was a considerable growth of *Chara fœtida*. Dr. Garrett, the Medical Officer of Health, says: "This plant is infested at all times with parasites, but during the time its cells are breaking down, the entire bulk of water contained in the reservoir swarms with living organisms, varying in size from the *Entomostraca* that are easily visible to the naked eye, to the most minute *Protococci* and other unicellular organisms which require a high power of the microscope to be distinguished." Species of *Volvox* were very numerous; species of *Nostoc* and filaments of *Oscillatoriæ* were also found. *Paramecia, Vorticellæ, Rotiferæ, Anguillulæ*, were also observed. The cleansed reservoir was dressed with lime and the water again turned in. All went well until the corresponding week of the following year, when the water from the same set of reservoirs again developed the fishy odour and flavour.

This time, however it was reservoir B which was chiefly affected, though the water in C was not destitute of odour. The water in the covered reservoir, A, remained free from algoid growth and was odourless. In C *Chara* was again developing, whilst in B the growth was abundant. This, Dr. Garrett thinks, proves conclusively that the *Chara* is the cause of the trouble. It is worthy of remark, however, that he found *Lyngbya muralis* parasitic on this plant, and that Dr. Farlow of Harvard University, in the Bulletin of the Bussey Institution for 1877, ascribes a peculiar suffocating odour as being due to the presence of this species of *Nostoc* in potable waters. A similar odour, he says, is produced by other species of *Lyngbya* and *Oscillatoriæ*, whilst *Beggiatoa* (the so-called sewage fungus) gives off a sulphurous odour, and decaying *Nostoc* a more disagreeable odour of pig or horse-dung. *Pari passu* with the development of the fishy odour in the Cheltenham water, the amount of organic matter (as measured by the organic ammonia and the permanganate required for oxidation) also increased therein, and to distinguish this from pollution entering the reservoir from without, Dr. Garrett calls it "natural" contamination. The Cheltenham water supply is naturally very pure and has a hardness of 7 to 11 degrees. In this latter respect, therefore, it differs from the other waters which have been mentioned as similarly affected, since all are surface waters of the softest character. At Gloucester, however, which also lies in the Severn valley, and which is supplied with a water from a similar source, there have been from time to time complaints due to the same cause. Invariably these odours develop in the autumn, but in certain years only, hence we may reasonably infer that the climatic conditions have been especially favourable for the growth of the particular organism or organisms which by their metabolic changes, or by their degeneration or decay, give rise to the foul-smelling compounds which taint the water. The drinking of such waters is not

recorded to have caused any illness, or any disagreeable effects beyond a sensation of nausea. The water, however, cannot be considered to be wholesome, and if there is no alternative supply it should be well filtered and boiled before use. Boiling alone will, in some cases, entirely remove the odour, whilst in others it appears to accentuate it unless the organisms producing it have been previously removed by filtration.

Small eels have been found in water-mains, and these by their decomposition have been known to impart a disagreeable odour to the water drawn therefrom.*

A recent case of somewhat similar character occurred in a small Essex hamlet obtaining its water supply from a pond. The water acquired a disgusting odour in the early summer, and I found that during the previous winter, which had been very severe, the water had been frozen into one mass of ice. After the thaw a quantity of dead fish had been removed, but apparently some had remained in the pond, and with the advent of still warmer weather these were decomposing rapidly, and the products of the putrefactive processes were tainting the water. In another case a water flowing from a disused mine acquired a most offensive odour; from the microscopical and chemical examination of the water I concluded that some animal had fallen down the shaft, which was on the hill above, and had been killed, and that its body was decomposing and polluting the water. Dead animals (from mice to babies) have been found in cisterns and tanks used for storing water when the development of some peculiar flavour has caused them to be examined. That putrid animal matters often contain poisons of the deadliest character is well known, hence waters containing any products of such decomposition should be looked upon as especially dangerous.

* "Eels in Water-Mains of the East London Waterworks," *Local Government Board Report*, 1887.

Taste.—Smell and taste are often confounded, for many substances possessing very strong odours, and generally reputed to have equally characteristic and powerful tastes, are really tasteless. Vanilla, garlic and assafœtida may be cited as examples. If the sense of smell be lost, or be held in temporary abeyance by closing the nostrils, it will be found that these substances are perfectly insipid and flavourless. Doubtless many of the waters which have just been referred to as having fishy, aromatic, or other odours and tastes, are really tasteless. But odourless waters may affect the sense of taste. Thus a very small quantity of iron gives water an astringent inky flavour, whilst an excess of common salt makes the water saline or brackish. Rain water has a peculiar flavour, and freshly distilled water is most insipid. Without having a distinct flavour, however, waters vary much in palatability. A well-aerated, moderately hard water, such as is derived from wells in the chalk and oolite, and from deep springs, is the most palatable. Upland surface waters and stored or aerated rain waters are moderately palatable, whilst fresh rain water and most polluted waters are least palatable. Some shallow well waters containing very large amounts of oxidised sewage matters are exceedingly palatable, and every analyst and medical officer can recall instances in which such waters have been held in high esteem for their brilliancy, pleasant flavour, and sparkling character, until something has occurred which caused the water to be examined and its true nature discovered. Whilst a good water, therefore, should be palatable, it does not follow that because a water is very palatable that it is also very pure and well adapted for domestic purposes.

Turbidity.—A good drinking water should be quite bright and free from all suspended impurities. Substances in a very minute state of division render water opalescent, and settle very slowly, if at all. Larger particles of mineral substances, living organisms visible to the naked

eye, and vegetable and animal débris, cause a greater or less turbidity according to the amount present. Very often a water which looks quite clear in an ordinary tumbler is found to be opalescent or turbid when viewed in a tube 1 or 2 feet in depth.

Insoluble mineral matters usually deposit rapidly; clay, however, causes a turbidity which disappears very slowly and is sometimes very difficult to remove even by filtration. A public water supply with which I am acquainted was always more or less turbid. It was derived from chains of wells sunk in loam and sand, and after heavy rains the amount of suspended clayey matter gave the water a most unsightly appearance. Many endeavours had been made to clarify the water, including treatment with alum, and filtration through sand, vertical sheets of flannel, etc., but without ensuring really satisfactory results. At my suggestion filter beds were constructed of polarite and sand, and the water since has been delivered to the consumers in a perfectly clear and almost brilliant condition.

The nature of the suspended matter can often be distinguished by the unaided eye, and the trained observer may draw important inferences from such an examination; but more frequently the aid of the microscope has to be invoked to determine the character of the deposit. Finely-divided mineral matter brought down by rivers in flood times is said to be capable of causing diarrhœa (*vide* Chap X.). Dead organic matter, or débris, may be derived from decaying plants and animals. The presence of cotton, linen or silk fibre, of potato starch, spiral cells of cabbage and similar plants, fragments of paper, etc., indicate contamination with sewage, and therefore that the water is of a dangerous character. Whatever the source, any considerable quantity of such impurities necessarily impairs the quality of the water.

The varieties of living organisms found in water are innumerable. Many are so minute as to require the

highest powers of modern microscopes for their detection, and their identification is a matter of great difficulty and ofttimes impossible. These bacteria are probably found in all natural waters; but, generally speaking, the purer the water the smaller the number of bacteria it will contain. The purest deep-well waters are almost certainly entirely devoid of bacteria whilst held in the pores of the subterranean rocks from which they are derived, but as raised to the surface of the earth a few of these ubiquitous organisms invariably gain access either from the air or from the materials with which the water comes in contact, and then commence to multiply with inconceivable rapidity. In other waters the number of bacteria present varies, roughly speaking, with the degree of pollution, few being found in the purest waters, whilst a single drop of sewage-polluted water may contain hundreds of thousands of them. Professor P. Frankland, who has made a special study of this subject, says: "As regards the nature of the bacteria found in natural water, they are for the most part bacilli, micrococci being comparatively rare, whilst spirilla are not unfrequently discovered, more especially in impure waters. Upwards of 200 different forms or species of micro-organisms have been already found in water, and although by far the majority of these are presumably perfectly harmless, a number of well-known pathogenic forms have also been discovered." Amongst these are the bacillus of typhoid fever, of cholera, of tetanus, of anthrax, and of tubercle. Singularly enough these pathogenic organisms retain their vitality longer when introduced into sterile water than when added to a natural water containing the ordinary water bacteria. Exposure to sunshine appears to have a most destructive effect upon all bacteria, but Professor Frankland thinks "it can only be in very shallow bodies of water, and in the superficial layers of deep ones, that it can exercise its power."

The minuteness of these organisms is such that it is

probable that they never occur even in polluted waters in such quantities as to render it opalescent to the unaided eye. Doubtless their presence would be revealed in the track of Professor Tyndall's concentrated ray of light, just as particles of dust are revealed by a sunbeam.

The presence of the spores and mycelia of the higher fungi indicates impurity probably derived from sewage, since the latter invariably contains phosphates, without which these forms cannot live.

Algæ, diatoms, and desmids are found in open wells, ponds, lakes, and running streams, and, as we have seen, some forms are believed to be the cause of the peculiar odours sometimes developed in practically stagnant water. Apart from this, their presence is of little importance, more especially as they are easily removable by filtration. These forms of vegetable life (unlike most fungi) do not depend upon decaying vegetable and animal matter for their sustenance, whilst the lower forms of animal life, next to be referred to, can only exist in waters containing such substances, and which therefore are more or less impure.

The lowest forms of animal life are only found in waters containing organic matter in solution. This organic material may, however, be merely derived from decaying vegetable matter, such as is found in the water of bogs and marshes, but these, nevertheless, cannot be considered as wholesome for drinking purposes. Ciliated animalculæ also abound in stagnant water, and Hassall noticed that in the Thames *Paramecia* were abundant below Brentford, where the river was polluted with sewage, whilst they were rare higher up the stream where the water was comparatively pure. The higher forms of life do not necessarily denote impurity, but the presence of worms or of their ova or embryos is especially objectionable, since these may be forms which can live and develop in the human system and produce harmful effects (*vide* Chapter IX.). Eels have been found in water mains, and in Chicago lately snails

(*Bythenia tentacula*) were found in water which had passed through the mains.

The Soluble Constituents of Potable Waters.—The substances in solution may be of mineral or of organic origin, the former derived from the rocks with which the water has been in contact, and the latter from disintegrating or decomposing animals and plants, from manured soils, sewage, etc.

Organic matter of any kind is objectionable. That which is derived from peat merely is least, that from sewage most, obnoxious. In passing through soil, however, organic matter becomes more or less completely oxidised,—the carbon into carbonic acid gas, and the nitrogen into ammonia, nitrous or nitric acid, the two latter of which, acting upon the carbonate of lime present in all soils, form nitrites and nitrates, liberating an additional amount of carbonic acid. This dissolves in the water, and gives the sparkling character so often observed in water from shallow wells sunk in polluted subsoils. This process of purification will be discussed more fully in a later section, whilst the significance of the presence of ammonia and of nitrites and nitrates — substances which in themselves are perfectly harmless—will be better treated of when the interpretation of the results of analyses is being considered. Although dissolved organic matter is objectionable, it is only when present in some quantity, as in water from swamps and marshes, and water highly polluted with sewage, that the organic matters themselves are likely to have any baneful effects. Even sewage-polluted water may be imbibed for years without producing any appreciable effect upon the health; but sooner or later the specific poison of typhoid fever, cholera, diarrhœa, or other disease is introduced by the sewage, and an outbreak almost inevitably follows. Polluted waters, and the diseases which have been attributed to their use, will be considered in the next chapter.

The total amount of saline matter permissible in a

drinking water depends in a great measure upon the nature of the salts. No hard and fast line can be drawn, but the best waters rarely contain more than 20 grains of mineral matter per gallon. When 100 grains is reached the water becomes rather of the character of a "mineral" than a "potable" water. The analyses already given show the wide variation which exists in the amount of inorganic matter contained in water used for public supplies, both when obtained from similar and from diverse sources. Thus the exceedingly pure lake water supplied to Glasgow contains less than 5 grains of solid matter per gallon, whilst the equally pure water supplied from deep chalk wells to many towns in Essex contains from 70 to 100 grains of saline matter per gallon. These deep-well waters, like many others derived from more superficial sources near the coast or the banks of tidal rivers, contain a considerable amount of common salt, but where the amount is not sufficient to more than suggest the presence of this ingredient to the taste (about 50 grains per gallon) it appears to be quite harmless. More than this would probably not be tolerated, though it might be exceedingly difficult to prove that it was otherwise obnoxious.

These saline deep-well waters also contain much carbonate of soda, in certain cases sufficient to exert a prejudicial effect upon plants when used for watering purposes, yet apparently without the slightest influence upon the human organism.

With reference to the alleged influence of the hardness of water upon health, the Rivers Pollution Commission, the Royal Commission on Water Supply, and other Commissions, received and considered a large mass of evidence. A commission appointed in 1851 to consider the London water supply, reported that "an aerated water is manufactured and safely consumed to some extent, which contains 92 grains of carbonate of lime per gallon, instead of 12 or 14 grains, as in Thames water. The portion of lime and

magnesian salts in the water drunk must indeed be greatly exceeded in general by the quantity of the same salts which enters the system in solid food. The only observations from which an inference of the lime in water in deranging the processes of digestion and assimilation in susceptible constitutions has been conjecturally inferred, have been made upon waters containing much sulphate of lime and magnesia, as shallow-well water, or the hard selenitic water of the new red sandstone, and have no force as applied to the Thames and its kindred waters, as the earths exist in these principally in the form of carbonate." A French Commission reported that the evidence received tended to prove that in hard water districts the inhabitants had a better physique than in the soft water districts; and a Vienna Commission reported in favour of a moderately hard water for a similar reason. The Rivers Pollution Commissioners prepared tables of death-rates of a large number of towns divided into three groups: (1) those supplied with soft water; (2) those supplied with moderately hard water; and (3) those supplied with hard water, and concluded that, "Where the chief sanitary conditions prevail with tolerable uniformity, the rate of mortality is practically uninfluenced by the softness or hardness of the water supplied to the different towns; and the average rate of mortality in the different water divisions varies far less than the actual mortality in the different towns of the same division." The evidence received by this commission also showed that in the British Islands the tallest and most stalwart men were found in Cumberland and the Scotch Highlands, where the water used is almost invariably very soft. It appears to be impossible to prove that, so far as health is concerned, either soft or hard water has the advantage; but there is a general consensus of medical opinion in favour of soft water. The opinion so often expressed that hard waters tend to produce gravel and calculus appears to have no foundation in fact—at least no

proof of such affections being more common in hard water districts than in soft has ever been forthcoming. That hard water tends to produce digestive derangements is believed by many medical practitioners, but my own impression is that such derangements, if they ever occur from this cause, are only temporary, and are induced in those who, having been long accustomed to the use of soft water, for some reason have changed to a hard water. After such a change it is conceivable that the system may take time to accommodate itself to the altered circumstances. In an article in *The Asclepiad*, Sir B. Ward Richardson refers to the use of hard water in certain fashionable watering-places, and attributes to it an injurious effect upon the health of the visitors. The first few days of quiet and change produce a beneficial effect, then dyspeptic symptoms set in—flatness, constipation, pain in the stomach, sleeplessness, etc.; the person then becomes low-spirited and possibly somewhat hysterical, the kidneys get out of order, and much pale-coloured urine is passed. All these symptoms, Dr. Richardson believes, in nine cases out of ten, are due to the hardness of the water and nothing else. That hard water is superior to soft on account of its greater palatability is probably also a fallacy. The palatability depends more upon the degree of aeration, and as a rule hard natural waters are better aerated than soft waters. The insoluble lime soap formed when washing in hard water is difficult to remove from the pores of the skin, and it causes, more especially in those not accustomed to its use, an unpleasant sensation, as though the skin were not thoroughly clean, and may cause a roughness of the cuticle and affect the complexion. It has even been suggested that the insoluble soap or curd, by clogging the pores or outlets of the sweat glands, interferes with the proper discharge of the functions of these glands and gives rise to pimples. By horse trainers soft water is preferred, hard water being credited with producing a "staring" coat, which is certainly not indicative of perfect health.

For washing purposes the superiority of soft water is undoubted. Apart from the use of soap, the detergent qualities of a water containing very little calcareous matter in solution are more marked than in waters containing a large proportion of such substances; but when soap is used, all the latter have to be removed before the soap dissolves in the water, and so a certain amount is wasted. The first action of the soap is to soften the water, and this is a very expensive method. The insoluble curd produced adheres to the articles being washed, and requires additional time and labour and soap to remove it. Where a hard water only is available for a public supply it is much cheaper, as we shall see in the sequel, to soften the water by the use of certain chemicals before supplying it to the consumers.

For other domestic purposes also soft water possesses many advantages. Before a Royal Commission Dr. Holland stated that soft water extracted the strength of tea twice as well as hard; and Professor Clark gave the opinion that, as the result of his experiments, hard water was quite unfitted for making tea. Too much stress, however, cannot be laid on this evidence, since the increased solvent power of soft water is mainly upon the tannin and astringent principles, the most objectionable constituents of the tea-leaf, and waters whose hardness is due to the presence of carbonates, become much softer when well boiled from the deposition of the lime salts as a fur upon the sides of the kettle. Monsieur Soyer, the famous cook, said that hard water gave cabbages, greens, spinach, asparagus, and especially French beans, a yellow tinge, and that the boiling process had to be prolonged, entailing an additional expenditure for fuel. For boiling meat or making soup it was not so good as soft water, the latter appearing to open the pores of the meat, whilst hard water compressed them. Soft water extracted the flavour of both vegetables and meat, and the juice or gravy of the latter much better

than hard water. Soft water evaporated one-third faster than hard water. For cooking purposes he would in every way "give the preference to soft water." The furring of kettles and boilers is also an objection to the use of hard water. A furred vessel requires more heat, and therefore increases the amount of fuel used and of time required to raise the water to any given temperature. The metal of which the vessel is composed gets unnecessarily hot, and if at such a time the fur should crack and the water come in contact with the superheated metal, it may determine a fracture. In boilers used for working engines by steam such an accident has often caused an explosion. For such purposes, therefore, hard water is very unsuitable.

But are there no objections to be urged on the other side to the use of soft water for domestic purposes? With one exception there is apparently no disadvantage in the use of the softest of waters. The exception is the proneness of certain soft waters to act upon metals, to dissolve lead and zinc, and to corrode iron pipes. This subject will be again referred to in Chapter IX., and when treating of storage cisterns, mains, and service pipes. The objection only applies to waters with a temporary hardness of less than 2 or 3 degrees; but such waters are at the present time being supplied to enormous populations, and the extent of its deleterious effect upon the consumers is only just beginning to be realised.

To sum up: The ideal of a potable water is one which is colourless and odourless, and which is free from all organic matter, and from all but the merest trace of the products of the oxidation of such matter, and which, while containing just sufficient carbonate of lime to prevent action upon metals, contains but little of any other saline constituent. That whilst a small amount of organic matter, if of peaty origin, is not very objectionable, the slightest trace of unoxidised sewage is an indication that the water is dangerous. That for all domestic and manufacturing

purposes a soft water is preferable to a hard water. That a hard water, in which the hardness is chiefly due to the presence of carbonates,—that is, in which the hardness is chiefly temporary—is preferable to a water which is permanently hard from the presence of sulphates. That hard waters, in which the hardness is due to the presence of magnesian salts (the sulphate more especially), are more objectionable than those in which the hardness is due to lime salts. That deep-well waters containing a moderate amount of common salt and of carbonate of soda, appear to be quite free from objection for domestic purposes. It should, however, be added that such waters, especially if they contain chloride of magnesium, as they usually do, injuriously affect "boilers," causing them to leak at the rivets and corroding the taps, so entailing expense in repairs and shortening the life of the apparatus. For this use, therefore, they are not to be commended.

The following recent analyses, made in my laboratories, show the saline constituents of pure waters from a diversity of geological sources. Those given are selected as being more or less typical, but it must be remembered that considerable variations occur. All results are expressed in parts per 100,000.

1. *Chalk, Exposed*:—

Calcium carbonate	16·0
Calcium sulphate	2·4
Calcium nitrate	2·15
Calcium chloride	0·55
Magnesium chloride	0·6
Sodium chloride	2·0
Silica, etc.	1·3
Total	25·0

2. *Chalk, beneath London Clay :—*

Calcium carbonate	1·9
Magnesium carbonate	1·4
Sodium carbonate	23·3
Sodium sulphate	8·6
Sodium chloride	52·95
Potassium nitrate	0·25
Silica, etc.	1·6
Total	90·0

3. *Thanet Sands, underlying the London Clay :—*

Calcium carbonate	2·0
Magnesium carbonate	1·55
Sodium carbonate	28·0
Sodium sulphate	18·35
Sodium chloride	25·6
Silica, etc.	1·5
Total	77·0

4. *New Red Sandstone :—*

Calcium carbonate	6·6
Magnesium sulphate	3·0
Magnesium chloride	1·8
Sodium nitrate	3·95
Silica, etc.	1·15
Total	16·5

5. *Lower Greensand :—*

Calcium carbonate	9·3
Calcium sulphate	1·65
Magnesium chloride	1·0
Sodium chloride	0·75
Sodium nitrate	1·25
Silica, etc.	1·55
Total	15·5

6. *Ashdown Sands* :—

Calcium carbonate	7·9
Magnesium carbonate	2·1
Ferrous carbonate	0·4
Sodium sulphate	4·85
Sodium chloride	6·1
Sodium nitrate	0·8
Total	22·15

7. *River Dee Water* :—

Calcium carbonate	8·5
Magnesium carbonate	0·4
Magnesium sulphate	3·4
Sodium sulphate	1·6
Sodium chloride	3·6
Silica, etc.	1·0
Total	18·5

8. *Magnesian Limestone* :—

Calcium carbonate	14·0
Magnesium carbonate	1·05
Sodium carbonate	1·85
Sodium sulphate	2·8
Sodium chloride	3·8
Potassium nitrate	0·3
Silica, etc.	1·7
Total	25·5

9. *Moorland Surface Water* :—

Calcium carbonate	0·5
Calcium sulphate	1·15
Magnesium chloride	0·5
Sodium chloride	0·7
Silica, organic matter, etc.	1·35
Total	4·2

10. *Subsoil Water—Gravel*:—

Calcium carbonate	17·2
Magnesium sulphate	4·0
Calcium sulphate	5·8
Sodium chloride	6·1
Sodium and potassium nitrate	1·7
Silica, etc.	2·2
Total	37·0

11. *Subsoil Water—Loamy Soil*:—

Calcium carbonate	23·4
Calcium sulphate	17·6
Calcium chloride	14·1
Magnesium chloride	11·5
Sodium chloride	24·6
Potassium nitrate	3·7
Silica, etc.	3·1
Total	98·0

The following is an example of an impure water:—

12. *Subsoil Water—Gravel—Surface highly manured*:—

Calcium carbonate	14·0
Calcium sulphate	31·3
Magnesium sulphate	5·5
Magnesium chloride	7·5
Sodium chloride	17·5
Potassium nitrate	22·8
Sodium nitrate	17·0
Organic matter, silica, etc.	4·7
Total	120·3

CHAPTER IX.

IMPURE WATER AND ITS EFFECT UPON HEALTH.

A HYGIENICALLY pure water has already been defined as one in which the inorganic and organic substances present are so small in amount as not appreciably to affect its physical properties, or render it unfit for domestic purposes. Accepting this definition, it is obvious that there is no sharp line of demarcation between the pure and impure. Often the difference is one of quantity rather than of quality, and, as will be found when the interpretation to be put upon the results of chemical and bacteriological examinations are being considered, opinions often differ as to what should be considered as pure and safe, and as impure and unsafe. Even waters which are merely hard, but otherwise of excellent quality, are, as we have seen, strongly suspected to cause dyspeptic symptoms in certain individuals, more especially if not previously accustomed to their use. The effects produced upon health by impurities of mineral origin differ from those produced by living organisms which are capable of multiplying within the system and causing specific disease. Dead organic matter appears often to be innocuous in itself, but is believed to cause diarrhœa occasionally. As this affection is also often produced both by soluble and insoluble mineral impurities, it may appropriately be considered first.

Diarrhœa.—A water containing an excess of magnesium, calcium or sodium sulphate, or of magnesium chloride, will be more or less aperient in its action, the effect depending

in part upon the amount of the salts present, and in part upon the constitution, etc., of the person drinking it. Finely-divided mineral matter—such as clay, scales of mica, etc., often found in turbid river water—has been repeatedly known to cause diarrhœa, probably by irritation of the mucous membrane lining the alimentary canal. Suspended vegetable débris has also been credited with producing the same effect. Pond water containing much vegetable matter (infusion of dead leaves, algæ, etc.), is well known to have a tendency to produce diarrhœa, especially amongst families who have not previously drunk such water. Sewage-polluted water has frequently caused outbreaks of this disease—sometimes with decided choleraic symptoms. These outbreaks, however, must be distinguished from those of true cholera, which can only be induced by specific pollution. The autumnal diarrhœa so prevalent in certain districts appears to have little, if any, connection with the water supply; but it has been asserted that water stored in reservoirs or cisterns during hot weather has a tendency to cause diarrhœa, especially if the temperature of the water reaches 60° F.

The various ways in which water may be polluted and cause diarrhœa are exemplified in the following cases, selected out of many found recorded in the reports of medical officers of health, in medical journals and elsewhere:—

During the Mexican War (1861-62) the French troops, when at Orizaba, were compelled to drink water impregnated with sulphuretted hydrogen, and suffered from diarrhœa and flatulency; the eructated gases had the offensive odour of rotten eggs.

At Salford Gaol, some years ago, an outbreak of diarrhœa occurred amongst the prisoners using water which passed through a certain tank. The warders, who used water from the same source, but which had not been stored in the tank, were not affected; and when the prisoners were supplied

with the same water as the warders, the diarrhœa ceased. Upon investigation it was found that a pipe terminating immediately over the surface of the water in the tank was in direct communication with a drain. Probably, therefore, the water had absorbed drain air, and possibly micro-organisms, and so become polluted.

Early in 1891 an epidemic of diarrhœa occurred at Lincoln. The symptoms were severe, but in no case fatal. Dr. Harrison, the Medical Officer of Health, says in his report: "I consider it was due to the contaminated state of the drinking water. The disease attacked people in Lincoln, Bracebridge, and the County Asylum, where, out of 750 inmates, 73 suffered. . . . In Upper Bracebridge, within 50 yards of the asylum, no case of diarrhœa was reported. These people were exposed to the extreme cold, but had a different water supply. At the time of the outbreak the supply was chiefly from the river Witham, which had for some weeks been frozen. The water was turbid, and had an offensive smell when heated, and contained a large excess of organic matter."

At Sedgley Park School in 1874 the contamination of the water supply by ordinary sewage was followed by an outbreak of diarrhœa and sickness, associated with great languor and prostration. The defective drain was repaired and the attacks ceased.

In a large factory in Schenectady, New York, employing 2,000 hands, much inconvenience was felt, independent of season, from prevalence of diarrhœal diseases amongst workmen, sometimes 10 per cent. of the employés being affected. The company substituted distilled water for that from the river Mohawk, allowing no other in the works. The improvement in the health of the hands was so marked that arrangements are being made to supply the families of the operatives as well, and another firm is about to adopt the same practice. (*Thirteenth Report, State Board of Health of New York*, p. 514).

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Diarrhœa of a dysenteric character, or possibly true dysentery, may also result from the use of impure water. Many outbreaks have been described by medical officers on service in tropical countries, some traced to suspended matters brought down by floods, others to the fouling of the water by cesspit oozings and fæcal soakage, others to water collected from near where a large number of bodies had been interred, and still others to the use of water which appeared only to be brackish. In many cases, when a purer supply of water was obtained, the epidemic ceased. Thus in 1870 a severe epidemic of dysentery occurred amongst certain of the troops at Metz who used water from wells which were found to be polluted with fæcal soakage. These wells were closed and the epidemic came to an end. In 1881 the wells were again used for supplying drinking water to the garrison, whereupon the disease once more broke out, but disappeared directly when the wells were again closed. At Prague, in 1862, an outbreak of dysenteric diarrhœa followed the pollution of the shallow wells by an overflow from the sewers. In 1840 and 1845 Dr. Hall observed that dysentery became epidemic in Tasmania amongst the population drinking stagnant water, whilst the convicts and others who used pure well waters entirely escaped. Many instances are also recorded in which the water from running streams was drunk with impunity, whilst that from the standing pools caused diarrhœa.

Outbreaks of dysentery occurred at Millbank Prison (London) in 1823 and 1824, which Dr. Latham, after a most exhaustive inquiry, attributed chiefly to the use of a polluted water supply.* More recently (June, 1894) Dr. George Turner has investigated the cause of similar outbreaks at the Suffolk County Asylum at Melton. He says: "The various forms of dysentery usually arise from the use of polluted water or decomposed food, the deleterious action

* New Sydenham Society *Works* of Dr. P. M. Latham, vol. ii.

of these two causes being frequently assisted and intensified by bad hygienic conditions, such as insufficient nourishment, defective drainage, want of proper ventilation, etc. . . . In fact the use of bad water is by far the most common origin of dysentery, and I have no doubt whatever, occasioned the late outbreak. Probably former epidemics were due to a similar cause." This interesting report will be again referred to. The water was derived from two deep bored wells which had been most carefully constructed, and which yielded a water believed to be of the highest degree of purity. Yet Dr. Turner was able to prove that the water in the bores was polluted by leakage, and to this pollution by subsoil water the periodical epidemics were to be attributed. As all the sanitary arrangements, including the drainage, were in a very satisfactory condition, the subsoil water could not be fouled by soakage from cesspools or defective drains, but that it was specifically infected seems proved by the report. One form of dysentery, at least, is due to the action of an animal known as the "amœba coli," and it is interesting to note that Dr. Turner found an amœba both in the drinking water and in the water of the subsoil through which the bore-tubes passed. The recent researches of Professor Klein seem to indicate that the *Bacillus enteritidis sporogenes*, found in all sewage, and therefore in sewage-polluted water, may be the cause of certain outbreaks of epidemic diarrhœa.

Diseases caused by the Mineral Constituents.

Goitre.—That enlargement of the thyroid gland may be caused by drinking certain waters is a well-known fact, and it seems probable that this effect is produced by some one or more of the minerals dissolved in it; but unfortunately we do not know the nature of the goitre-producing substance, and it is impossible therefore to ascertain beforehand whether a given water will cause the disease or

not. In England goitre is or was most prevalent in parts of Derbyshire and Nottinghamshire, and also in the valleys of Sussex and Hampshire. In nearly all countries there are localised areas in which the affection appears to be endemic, and it has usually been noted that the waters of such districts contained much lime and magnesia salts. Thus at Kamaon, in the province of Oude (N.W. India), Dr. M'Clellan found that of the population drinking water collected from granite, gneiss, and green sandstone, not one was affected with goitre; of those obtaining water from clay, slate, mica, and hornblende, under half per cent. were affected, whilst one-third of the whole population deriving their water supply from the limestone rocks suffered from a more or less severe form of the disease. Dr. Wilson, on the other hand, found that at Bhagsoo goitre was very prevalent, yet the waters here are very soft, and almost free from lime and magnesia compounds. Other constituents, such as sulphide of iron, copper, etc., have been suspected to be the cause of goitre, because in certain districts where the disease prevailed such impurities were present, but observers have not been slow to point out that such explanations are not generally applicable. That the disease is really attributable to the water and not merely to the influence of soil, site, etc., appears to be fully established. A French Commission sitting in 1873 reported that at Bozel in 1848 there was a population of 1,472, of whom 900 were goitrous, whilst at St. Bon, a village some 2,600 feet higher, there was not a single case. When the water supply of St. Bon was laid on to Bozel, the disease decreased so rapidly that in 1864 there were only 39 people in the latter village found to be suffering therefrom. In the French military journals there are many cases quoted, proving that certain waters will produce goitre in a few days, and that persons were in the habit of resorting to the use of these waters to escape conscription. On the other hand it has been pointed out that in certain villages

supplied with water from the same source, some were afflicted with goitre, whilst others were not. Hirsch, in summing up all the evidence as to the cause and distribution of the disease, says: "As to the nature of this goitrous virus and its means of conveyance, it is impossible to form a well-grounded opinion. Its existence and development would appear to depend upon certain definite kinds of soil, such as a soil containing dolomitic rock, and it would appear to occur principally in water. Whether its nature is organic or inorganic is a question that evades our answering."

Plumbism.—Natural waters rarely contain lead, and probably never in sufficient quantity to produce any evil effects; but certain waters, both hard and soft, containing very little or no alkaline carbonates, dissolve traces of the metal if conveyed through leaden service pipes. The amount of lead dissolved depends upon the character of the water, the time during which it is in contact with the pipe, the temperature, pressure, and possibly upon other factors of which we as yet know but little. The effects produced by the small amount of lead dissolved are rarely so serious as to cause death, or even the severe colic or paralysis characteristic of lead poisoning, and for this reason the injurious results of the long-continued use of waters so polluted are only gradually receiving recognition. Amongst the effects produced are a state of listlessness, leading to melancholia, depression, and actual insanity, pallor and debility, constipation and indigestion, paralysis, colic, gout, kidney disease, blindness, etc. Still-births increase, and the children of lead-poisoned parents are rickety and ill-developed. That the effects are much more serious and widespread than is generally supposed, is being rendered evident by the reports of the medical officers of districts in which such waters are used. Thus Dr. Hunter, the Medical Officer of Health for Pudsey (Yorkshire) says in his report for 1891: "Lead poisoning has been common in

the town during the year. This is a matter that, from its importance, claims your serious attention. As lead poisoning is not often registered as a primary cause of death, it does not make a show in the death-list, but there is no doubt that the death-rate is greatly increased by its prevalence in the town, the deaths being registered as caused by diseases of the various organs of the body that have been affected by the lead. But if even no death could be put down to lead poisoning, the amount of pain, suffering, and misery caused is widespread, and can only be appreciated by the sufferers. There is a mistaken feeling amongst those who are lucky enough to escape, that the risks of this kind of poisoning are exaggerated." Dr. Hunter found in the water first drawn from the taps in the morning from .2 to 1.3 grains of lead per gallon. Soon after the report appeared, the Bradford Corporation, who have control of the water supply, began to add 3 grains of chalk to each gallon, and have continued so to do ever since. The result has been that no case of lead poisoning has been recorded for several years. Dr. Barry, of the Local Government Board, estimates that in the West Riding of Yorkshire alone 600,000 persons are liable to lead poisoning by the drinking waters with which they are supplied.

Water which has stood in the pipes all night naturally becomes most seriously contaminated, and probably, were the users careful to allow this to run to waste before drawing any for drinking purposes, cases of lead poisoning would be less common. The water which afterwards passes through the pipes will contain an exceedingly slight trace, unless a great length has to be traversed. Such waters will of course take up the metal if stored in lead cisterns, or if drawn from a well through a leaden pipe. The quantity of lead necessary to produce any ill effect varies in different individuals. The great majority appear to be able to eliminate the poison as fast as it is introduced, but in others it tends to accumulate until the amount stored in

the system is sufficient to affect the function of some organ or even to induce a diseased condition. The actual amount of lead consumed by any individual in the districts above referred to cannot be estimated, since the quantity present in the water may have varied almost with every time of using. It is possible that there are individuals so susceptible that the most minute quantities will in time produce an appreciable effect. The only safe course is to prevent waters with a plumbo-solvent action coming in contact with the metal, by the use of tin, iron, or copper for the pipes and of slate for the cisterns. The so-called tin-lined lead pipe is not to be commended, since, during the process of lining, the tin dissolves a small amount of lead, forming an alloy which appears to be almost as easily acted upon by water as lead itself. Some time ago I found a large trace of lead in a water which was supposed never to have been in contact with that metal. It was stored in tinned copper and passed through block tin pipes. The lead was traced to the tin lining of the copper vessel, and the makers denied the possibility of there being any lead therein, and asked me to visit their works and see the process of "tinning." I availed myself of the opportunity, and found the tin melted ready for the work to be commenced. I was informed that this was "pure" tin, but upon further interrogating the workmen I ascertained that it was technically called "pure" tin for tinning purposes, and contained, if I remember aright, about 15 per cent. of lead, the latter being added to cause the tin to adhere to the copper. My correspondent, one of the partners in the firm, was himself ignorant of this fact. Tin-lined iron pipe, known in commerce as the "Health" pipe, is absolutely safe, and the best form of service pipe for all drinking waters. An interesting sample of water was recently submitted to me for examination. It was found that the leaden pipes from the hot-water cistern regularly split at the bends after being in use for about a couple of

years. The pipes from the cold water cistern were unaffected. The water proved to contain only about 1 grain of carbonate of lime per gallon, though it had several degrees of hardness. When cold it had not the slightest action upon lead, but after being boiled it attacked the metal so energetically that I have no doubt of its being able to erode the pipes in the manner described. Doubtless, at the angles slight fissures would be found in the lead, and by the prolonged action of the water these would ultimately extend right through the thickness of the pipe.

The various ways in which lead can be removed from water, and by which an "active" water can be rendered "inactive" will be described in a later chapter.

Diseases due to Specific Organisms.

Whilst waters containing impurities both of vegetable and animal origin are constantly being drunk with apparent impunity, yet in almost all cases it is found that sooner or later outbreaks of disease occur, pointing to some specific polluting material having gained access to them. The danger naturally is greatest where the filth which contaminates the water is derived from human excrement, whether it be discharged from sewers into our rivers, or oozes through a defective cesspit, cesspool, or drain into wells or tanks, or whether it percolates through the sewage-sodden ground around our habitations, and in an imperfectly filtered and purified condition reaches the subsoil water from which our supplies are derived. In such cases our observations only require to be continued sufficiently long to ensure an outbreak of some specific disease being recorded. Of this many illustrations will be given when typhoid fever and cholera are being considered. There are other diseases, however, which are due to specific organisms which apparently may occur in water free from pollution by sewage. Of these the most important is malaria, or

malarial fever, a disease which in many countries is far more prevalent than any other.

Malaria.—Malarial disease is at the present time almost unknown in England. Even in the districts in which ague was most prevalent, as in the fens of Lincolnshire and marshes of Essex, it is now but rarely met with. Whether this be due to better drainage or purer water supplies it is impossible to decide, probably both are important factors.

The organism causing this disease is usually introduced into the system by the bite of a certain species of mosquito; but its life history is not sufficiently well known to enable us to prove or disprove possible infection by means of drinking water. Swampy districts are most frequently malarious, but they are not necessarily so, and swamp water which is usually loaded with vegetable matter is frequently drunk without causing malaria. This is doubtless due to the fact that whilst the natural habitat of the malarial parasite discovered by Laveran is in tropical water-logged districts, yet it is not of universal occurrence in such districts, and may, under certain conditions, of which we are yet ignorant, thrive elsewhere. The disease, however, is only of interest here, inasmuch as there is evidence sufficient to warrant us in believing that one of the modes in which the malarial organism enters the system is with the drinking water. Thus Dr. Parkes, during the Crimean War, questioned the inhabitants of the highly-malarious plains of Troy, and found that it was universally believed "that those who drank marsh water had fever at all times of the year, while those who drank pure water only got ague during the late summer and autumnal months." Mr. Bettington, of the Madras Civil Service, who carefully investigated this subject, obtained very strong evidence of the production of malaria by drinking water. In one village he found that fever was prevalent amongst those who drank water from one source—a tank fed partly by marsh water—but absent amongst those who obtained water from other sources. In

another village in which fever was endemic, it entirely disappeared when a better water supply was obtained. In the Wynaad district, where malaria is very fatal, he says that it "is notorious that the water produces fever and affections of the spleen." Boudin relates that "on board a French ship-of-war bound from Bona to Marseilles, a malignant epidemic of malarial fever broke out at sea, 13 men dying out of a crew of 229, whilst 98 were more or less seriously ill, and had to be sent into hospital at Marseilles; it came out, on inquiry, that the vessel had shipped at Bona several casks of marshy water, which had given rise to lively dissatisfaction among the crew on account of its disagreeable smell and taste, and that not a single case of sickness had occurred among those of the crew who had drunk pure water." Notwithstanding such apparently conclusive evidence, many observers doubt the production of malaria by drinking water. Amongst the more recent ones may be cited Mr. North, who spent much time in investigating the cause of this disease in and around Rome. He observes that the healthiest parts of the city of Rome are supplied with water from springs which arise in a locality so unhealthy that there is great risk to health, and even to life, in passing the nights there during certain seasons of the year. He concludes that there is not sufficient proof of the disease being conveyed by water, notwithstanding that such a belief is universal in all districts in which the disease prevails.

Surgeon-Major R. R. H. Moore, in a recent article on "Water Supplies and Malarial Fever" (*Journal of State Medicine*, vol. vi., p. 116), criticises the evidence with reference to the outbreak on the ship "Argo," and quotes another account, which says that "during the passage of eighteen days salt provision had to be used owing to the scarcity of fresh water, and which, from being stored in old casks, quickly became bad. Under these insanitary conditions, disease of a serious nature set in, symptoms of

typhoid fever appeared, and about 30 of the soldiers died either on board ship or in lazaret at Marseilles." He contends that the great objection to most of the instances in which water is alleged to have caused malarial fever is that they have occurred in places where the disease is endemic, and where it is almost impossible to demonstrate positively that the poison did not enter the system through the medium of air. He is unable to understand how it is that the idea still holds its ground, considering how little there is to be said in support of it, unless it is due to the great influence of Parkes; for it is evident from his work that the water theory was a favourite one with him. Many continental epidemiologists have given up this theory, but the most recent observers (Laveran, Babes, and Vandyke Carter) believe that the infection may be caused by the drinking water.

Enteric or Typhoid Fever.—The production of typhoid fever by the use of polluted drinking water is an indisputable fact, and the instances which can be adduced in proof of this statement are so numerous that it is difficult to make a selection. The following examples are given not only as illustrating such proof, but also on account of their being typical of outbreaks produced by the pollution of the water in most diverse manners. In some the source of the infected material was almost self-evident, in others the discovery of the mode by which the water became contaminated taxed the ingenuity and patience of the investigator to the utmost, whilst in others specific pollution could only be inferred.

At Lausen in Switzerland an outbreak of typhoid fever occurred * amongst that portion of the population which derived its drinking water from a certain spring. On the other side of the hill was a brook which passed underground, and it was suspected that this stream really fed the

* In August, 1872. *Deutsch. Arch. f. klin. Med.* Bd. xi., 1873, S. 237.

spring in question. When flour was added to the brook water, however, none of it made its appearance in the spring, but when salt was dissolved in the stream, its presence was soon after discovered at Lausen. Obviously the water in traversing the hill became filtered so completely as to remove all the particles of the flour, yet such filtration had failed to remove the typhoid poison, which it was proved had been introduced into the brook by the stools of a patient suffering from that disease. Shortly after the fouling of the stream typhoid fever broke out amongst those who used the spring water, 67 persons being attacked within 10 days.

In 1872 an epidemic occurred at Nunney (Somersetshire) which Dr. Ballard investigated on behalf of the Local Government Board. He found that the brook supplying the village with water had been specifically polluted by the drainage of a house into which typhoid fever had been introduced from without. 76 cases occurred amongst a population of 832.

In 1874 a serious outbreak at Over Darwen (Lancashire), was investigated for the Local Government Board by Dr. Stevens. It was proved that a patient who had contracted the disease elsewhere resided in a house the drain from which was blocked and defective at a point where it crossed a leaking water main. Dr. Stevens succeeded in demonstrating that the sewage was sucked into the water main freely and regularly. The disease spread rapidly, and no less than 2,035 persons, or nearly one-tenth of the whole population, were attacked within a very short period.

In 1882 a serious outbreak occurred at Bangor (N. Wales), which ultimately affected 540 persons out of a population of about 10,000. In May a case of enteric fever had occurred in an isolated house that discharged its sewage into a small stream which at a point lower down joined a larger stream, the Afon Gaseg, from which Bangor derived its water supply. During June two other cases

occurred in the above house, and specifically polluted sewage continued to find its way into the Afon. The filter beds were said to be very imperfect, and these were disturbed on 30th June by the bursting of a water main. Within a fortnight of this accident the outbreak commenced, attacking simultaneously various localities in the town.

In 1879 an epidemic occurred at Caterham and Redhill in Surrey. Within a fortnight 179 persons were attacked. Of the 143 houses first infected, 136 had their water supply exclusively from the public mains, and in the other 7 houses this water was occasionally used. Of the 2,258 houses in the two parishes, 1,343 derived water from the mains; the remainder were chiefly supplied from wells. Dr. Thorne, who investigated the outbreak, found that just prior to the outbreak, the Water Company had been enlarging their reservoirs and had sunk a shaft down to the conduit. One of the labourers employed in this conduit had contracted typhoid fever at Croydon, but was able to continue his work. Diarrhœa was profuse, and as he could not conveniently leave the shaft his motions were passed at the bottom and were afterwards washed into the conduit. "The outbreak took place simultaneously in Caterham and Redhill exactly fourteen days after the water supply had been befouled in this manner."

In 1880 a case of typhoid fever was introduced into the town of Nabburg (pop. 1,900) and spread among the inmates of the infected house; about a fortnight later other cases occurred amongst the inhabitants of the row in which this house was situated, and within the next fortnight about half (35 out of 77) the inhabitants were suffering from typhoid fever. Three out of the row of 17 houses and the poor's-house remained free from the disease, and it was found that these were supplied with water from a well, whilst all the others derived their water supply from a tank fed by a pipe which ran through a slop puddle. This slop puddle received the drainage from a dung-heap upon

which typhoid excreta had been thrown, and the water pipe was perforated at the part where it was covered by the filth. As soon as these pipes were repaired the epidemic ceased.

The danger which may arise from the proximity of a sewage farm to a water supply is well exemplified by the Report of Dr. Page to the Local Government Board on an outbreak of typhoid fever at Beverley (Yorkshire) in 1884. The sewage of the East Riding County Lunatic Asylum was disposed of upon a field next the Water Company's well and works, and the effluent water "following in the direction of the natural line of drainage" percolated towards the Company's premises. Certain defects were found in the well, and prior to the outbreak cases of typhoid fever had occurred in the Asylum. The total number of households invaded was 125, and there were 231 cases, 12 of which proved fatal.

In all the above instances the source of the specific pollution was discovered. In the following there was proof only of the contamination of the water by sewage. This must have contained the specific organism of typhoid fever, but the cases which introduced these into the sewage remain undiscovered, though in some instances the possibility of such specific contamination was proved.

In 1867 an outbreak of typhoid fever occurred at Sherborne in Dorset. Dr. Blaxall, who was instructed by the Local Government Board to investigate it, attributed it to the direct connection of the water supply pipes with the closet pans. Some of the taps to these pipes were broken. When the water was turned off at the mains, the foul air from the closet pans, or, if the pan happened to be full of excrement, actual fæcal matter could be drawn into the water pipes.

In 1873 Dr. Buchanan contributed a most important report to the Local Government Board on an outbreak of typhoid fever at Caius College, Cambridge. Twelve of the

fifteen cases which occurred were in Tree Court, and Dr. Buchanan could find no condition capable of explaining the outbreak but the pollution of the water in the branch main which supplied this court alone. He found that the closets in this court were the only ones in the College flushed directly from the main, and that on account of defects in the valve taps, when there was an intermission in the water supply a reflux of air and water took place into the main. There had been two intermissions during the term, one a fortnight before the first case, and the other a fortnight before a more general outbreak. Inside the pipes a dirty-looking layer was found, which upon analysis proved to be derived from sewage; hence doubtless not only sewer gas but also actual liquid filth had been sucked from the closet pans into the pipes.

In 1887 an interesting outbreak occurred in the Mountain Ash Urban Sanitary District (Glamorganshire), which comprises several mining villages. The cases ultimately numbered over 500, and the localisation was such as to throw suspicion upon one particular branch of the public water mains. The only possible explanation appeared to be the fouling of the water in this branch at a particular point. The ground was accordingly opened there, and it was found that the water main passed through some drains which had been "wantonly smashed" for this purpose, and the main itself was defective and leaking. Prior to the outbreak there had been intermissions in the supply, allowing the fluid filth by which the pipe was surrounded to be sucked into it, and so contaminate the water passing through that particular branch.

The following outbreak, due to polluted ground water, is typical of a large number which have been reported from time to time in districts deriving their water supplies from wells sunk in a polluted subsoil. At Terling, in Essex, an epidemic of typhoid fever occurred in 1867. Out of a population of about 900, no less than 260 were attacked

within two months. The wells supplying the cottages were in close proximity to the privies, cesspits, bumbies, and manure heaps. Towards the end of a period of drought a case of typhoid fever occurred which probably was imported Three weeks later, and after a heavy rainfall, the disease broke out with alarming violence. The well waters were proved at all times to be seriously contaminated, but until the introduction of the specific pollution the village had been free from the disease. In the filth-sodden soil the typhoid bacillus had probably found a suitable nidus for its rapid multiplication; thus the heavy rainfall would not only wash impurities into the wells from the surface, but wash the organisms out of the soil into the rising ground water which supplied the wells.

The very serious outbreak of typhoid fever which recently occurred (1897) at Maidstone is worthy of more detailed attention. Here the implicated water, though said to be derived from a spring, was really collected beneath the ground surface, and was nothing more than a very shallow well supplied with water directly from the subsoil, and indirectly through a series of adits, in this case consisting of drain pipes laid only 2 to 3 feet below the ground surface. The only houses near were a farm house upon higher ground, and a row of cottages on lower ground. Very much nearer, however, was an erection used for the temporary accommodation of hop-pickers, and, so far as I could see, without any sanitary conveniences whatever. From my examination of the locality, I should certainly say that both the farm and the cottages were without the sphere of influence, and could not possibly have contaminated the water. The top of the well, however, was not raised above the ground surface, but in a little hollow, and only covered by a wooden framework and lid. The hop-pickers, or anyone else for that matter, could micturate or defæcate in the hollow without let or hindrance, but it is not necessary to suppose that such direct pollution took

place. The subsoil water level was at this point close to the ground surface, and at the highest point above in the hop gardens the subsoil water cannot have been more than 2 or 3 feet from the surface, or the pipe drains would not have been laid at that depth. These drains ran under the hop garden, and it is the subject of common knowledge that such gardens are very highly manured. Assuming that this two or three feet of soil always retained its maximum purifying and filtering powers, no one would dare to assert that it was sufficient to prevent any specific polluting matter laid on the surface from entering the drains and passing into the well. But in dry seasons the soil becomes parched and cracked, and in this condition filth could probably be washed directly into the drains; in any case the filtering would be seriously reduced in efficiency. The study of this case therefore teaches no new lessons, and there is no cause for surprise that water from such a source should sooner or later become specifically infected, and produce an epidemic of typhoid fever. The case has been more particularly referred to because it has caused a great deal of needless alarm, and an unreasoning prejudice against the use of subsoil water for public water supplies.

In 1889 an outbreak occurred at New Herrington, Durham, 278 cases being reported between the 1st April and 7th June out of a population of 3,600. Dr. Page discovered that a deep well supplying the village was being contaminated by the sewage of a farm three-quarters of a mile away. This sewage discharged into a tank, and the overflow disappeared down a fissure in the ground and ultimately found its way into the well at a point 45 feet below the surface. Two tons of salt were put down this fissure and soon after the amount of chlorine in the well water began to rise, ultimately increasing from 4 grains to 24 grains per gallon. Specific pollution, however, was not demonstrated, as no case of typhoid fever was known to have occurred at the farm for years.

Dr. Maclean Wilson recently investigated for the Local Government Board an outbreak of enteric fever at Chester-le-Street, between Durham and Newcastle. Of the 1,100 houses in the village some 40 per cent. were supplied by the Consett Water Company, and some 60 per cent. by the Chester-le-Street Company. Of the 41 infected households, all but 2 derived water from the latter source, and these 2 were amongst the initial cases, "possibly not due to the cause producing the general outbreak." The Chester-le-Street Company draws its supply from the Stanley Burn, about two miles above the village. Above the intake quite a large population drains directly or indirectly into the stream. In a group of cottages at Southmoor a series of cases of typhoid fever had occurred in October, 1892, and January and February, 1893, and the bowel discharges of these patients passed into a stream which forms a tributary of the Stanley Burn. The filtration of this water before being supplied to the consumers does not appear to have been satisfactory. The outbreak may be said to have commenced on 14th November, 1892, and came to an end in mid-March. Dr. Wilson concluded that "there appeared nothing in the inter-relations of the sufferers by fever, nothing in the milk supplies used by them, and nothing in their sanitary surroundings in the least likely to afford a common source of infection. On the other hand is the fact that so many persons using the same polluted water suffered, while their neighbours who used other water escaped. Furthermore, there occurred shortly before each of two outbreaks of the fever, opportunity for the bowel discharges of enteric-fever patients gaining access to the particular stream which afforded the water supply of invaded households in Chester-le-Street."

The dissemination of typhoid fever by river waters is a subject of the greatest importance, and has already been referred to when rivers were being considered as a source

of water supply. As few rivers of any magnitude escape pollution by sewage, the great question is, whether such waters can safely be used for supplying towns with drinking water. That exceedingly polluted river water may be used for long periods without producing an outbreak of typhoid fever is undoubted, but can complete immunity be ensured? If the water used be drawn many miles below the lowest point of contamination, if it be thoroughly filtered, and every possible precaution be taken to avoid collecting water when the river has been disturbed by heavy rains and floods, is all danger removed? The answer to this would depend upon the amount of reliance to be placed upon the safeguards which depend upon human agency. Can all accidents be guarded against? Can perfect filtration be secured at all seasons and under all circumstances? To the temporary break-down of a filter bed, Koch attributes the recent outbreak of cholera at Hamburg (*vide* cholera). A similar accident might lead to an epidemic of typhoid fever, assuming that the river water were specifically polluted at the time. This coincidence of specific pollution and defective action of the filters may be an extremely improbable one, but the degree of probability depends upon many as yet imperfectly known factors, such as the length of time which the typhoid bacillus can live in river water, or in the sedimentary matter on its bed, the conditions under which mere filtration can be depended on to remove the organism, etc.

In 1891 Mr. Hiram F. Mills, a member of the Board of Health of Massachusetts, prepared for that board a report on "Typhoid Fever in its Relation to Water Supplies." He found that in Massachusetts the highest typhoid death-rates were not in the cities but in the towns supplied with well water. The introduction of purer water supplies had in all cases been followed by a decrease in the typhoid mortality, but in two cities, Lowell and Lawrence, with a population of 123,000, there had been during the previous

twelve months about one-third more deaths than in the city of Boston with four times the population. The cause of this excessive prevalence of typhoïd fever was investigated, and it was found that prior to the outbreaks the Lowell water supply had been contaminated by the fæces of typhoid patients discharged into Stony Brook, only three miles above the intake of the water-works. This pollution was followed in about three weeks by a very rapid increase in the number of deaths from typhoid fever in Lowell, and about six weeks later by an alarming increase in the number of deaths in Lawrence, whose water supply is drawn from the Merrimac River, nine miles from where the Lowell sewage enters the river. An examination of the water from the service pipes of the city of Lawrence led to the discovery of the typhoid bacillus therein. These two cities are the only cities in the State which draw their water for drinking from a river into which, within twenty miles above, sewage is publicly discharged. "The amount of sewage that has directly entered the river (Merrimac) and its branches during the chemical examination of the past three years is estimated to be about 1 gallon in 600 gallons of the river water passing Lawrence, and there has been no more impurity in the water, that could be detected by chemical analysis, than in about one-half of the drinking water supplies of the State obtained from ponds and streams: but the facts which have been presented, showing that these two cities have so much higher death-rate from typhoid fever than any other cities of the State, together with what is known of the relation of typhoid fever to sewage-polluted drinking water, are the strongest grounds for concluding that, even with the small amount of organic impurity in the water as shown by chemical analysis, the germs of this disease are able to pass, and do pass, from one city to the other in the water of this river." Experiments were made to ascertain whether the typhoid bacillus could withstand a temperature only a little above freezing-point

long enough to pass from the Lowell sewers to the water mains of Lawrence. It was calculated that the Lowell sewage would reach the intake of the Lawrence Waterworks in eight hours, and would pass through the reservoirs into the mains within ten days. Typhoid germs kept in ice-cold water were found to be killed somewhat rapidly, but it was not until the twenty-fifth day that all the bacilli had perished. Evidently, therefore, the typhoid-fever germs from the Lowell sewers may live in winter to enter the Lawrence mains in great numbers. The fact that more cases of fever occurred near the reservoirs than in the districts towards the ends of the mains is explained by the bacteriological examination of the water, which proved that the number of bacteria in the water gradually diminishes with the distance from the reservoirs. The Merrimac is a large, swift river, and Dr. Edwards denied that the *ejecta* of a few persons could possibly contain a sufficient number of germs to lay low some hundreds of people in Lowell. He elaborately computed the dilution which the *ejecta* had undergone, and came to the conclusion that the water theory involved a physical impossibility, and consequent *reductio ad absurdum*. A somewhat similar conclusion was arrived at by the Metropolitan Water Supply Commission after considering the evidence adduced for, and against, the theory of the Tees River water being the cause of the typhoid epidemic in the towns in that river valley. As we know nothing of the number of bacilli which a typhoid patient may discharge, nor of the number which are necessary to produce an attack of the disease, arguments and speculations of this character can have but little weight.

It is interesting to note that in 1892-93 another outbreak of typhoid fever occurred in the Merrimac valley, involving Lowell, Lawrence, and Newburyport. Dr. Sedgwick, who again conducted the investigation, found that in December, 1892, there was a marked increase in the number of cases

of typhoid fever in Lowell. It was predicted that Lawrence would soon suffer, and before long fever began to increase there; and at the same time a very unusual, and at first apparently unaccountable outbreak occurred at Newburyport, lying below these cities at the mouth of the Merrimac. Contrary to the advice of the State Board of Health, it was discovered that, owing to a scarcity of water, the company at Newburyport had for some time been drawing water from the river. "The occurrence of this epidemic in Newburyport," says Dr. Sedgwick, "and its apparent connection with the outbreaks in Lowell and Lawrence, must be accounted one of the most interesting phenomena in our whole series of investigations, and may serve to confirm the truth of the saying that 'no river is long enough to purify itself.'"

In the same year (1892), an outbreak of typhoid fever occurred at Chicopee Falls. Cases of fever had occurred above the intake of the Water Company from the Chicopee River; and everything pointed to this infection of the public water supply as the cause.

Tees Valley Epidemic.

The continued prevalence of typhoid fever in the Tees valley and the occasional occurrence of more or less extensive epidemics, caused the Local Government Board to instruct their inspector, Dr. Barry, to visit the district and fully investigate all the circumstances, and, if possible, discover the cause.

Two epidemic outbursts occurred here, one in September and October, 1890, and the other in January and February, 1891. Each outbreak was most marked during a six-week period. Out of 1,463 cases, 91 per cent. occurred in three out of the ten registration districts embraced by the Tees valley. These three districts comprised the towns of Darlington, Stockton, Middlesborough, South Stockton,

Ormesby, Normanby, Eston, and Kirkheaton, and the two rural districts of Darlington and Stockton. The possibility of these epidemic outbreaks being due to infected milk supplies, to defective systems of sewerage and drainage, or of faulty excrement and refuse disposal, was fully considered. Many insanitary conditions, of course, were found, but their distribution was not such as could afford, in Dr. Barry's opinion, a probable cause for the outburst of disease. Milk as a factor was easily excluded. When the water supply was examined, Dr. Barry found that nearly half the population in the above districts obtained their water from the river Tees through the works of the Darlington Corporation and the Stockton and Middlesborough Water Board.

During the first epidemic period 33 persons per 10,000 of those using Tees water were attacked with enteric fever, and only 3 amongst persons supplied with water from other sources. In the second epidemic the attack-rates were 28 and 1 respectively. The Tees water was therefore gravely incriminated, and its source was fully examined. It was found that, "either directly or indirectly, the drainage of some twenty villages and hamlets, as well as that of the town of Barnard Castle," is poured into the river above the intake of the water companies. Photo-lithographs, showing rubbish tips on the banks of the river, and the outlets of numerous drains and sewers, accompany the Report. The river, in fact, appeared to be utilised as a common sewer. The introduction of the specific organism of typhoid fever, and the failure of filter beds, it is argued, would necessarily lead to outbreaks of this disease amongst the users of the polluted water, and this is what Dr. Barry believes did occur just prior to both epidemics. Heavy floods, due to an abnormal rainfall, and to the melting of snow, washed down accumulations of filth, and shortly afterwards enteric fever became excessively prevalent. "Seldom, if ever," says Dr. Thorne, the

by surface water from highly manured land, and by a somewhat large population living in tugs, canal boats, and barges. The analyses of various samples of Trent water afford abundant evidence of this pollution; and prove also that the stream becomes defiled at so many points that no opportunity is afforded for the natural causes of purification to produce much effect. Night soil from several large towns is freely used upon land bordering on the stream, and much of the same filth is conveyed by boats plying upon it; and when these barges are unloaded we hear of the fluid filth remaining in the hold being pumped into the river. Notwithstanding this, throughout nearly the whole of its course the river water is used for domestic purposes, and regarded as "wholesome and harmless."

In the Gainsborough Rural Sanitary District, the Infectious Disease Notification Act had not been adopted, and the number of cases of typhoid fever which had occurred during recent years had to be ascertained by inquiry from local practitioners, some of whom could only give information from memory. Based upon statistics so obtained, Dr. Low shows that, during the previous four and a half years, the enteric fever attack-rate in the villages using well water only averaged 1.92 per annum per 1,000 population, whereas in the villages using Trent water the attack-rate was 29.3. From the number of villages and aggregate population, it is evident that the fewest cases occurred amongst the more scattered population; but whether the drainage and sewerage arrangements were satisfactory in the larger villages where enteric fever was more prevalent is not stated. Neither is the number of deaths from typhoid fever in each group given to confirm the deductions drawn from the estimated number of cases. Apparently the results of Dr. Low's investigations were communicated to the Parochial Committees of the villages most concerned, and the unanimity with which each declared that Trent water was not injurious, and that its

village was in a healthy state, is somewhat amusing. Where money has to be expended, the arguments which will convince a Parochial Committee that anything is wrong have to be very conclusive and clinching.

In the town of Newark about half the population was until recently supplied from the Trent, and the other half from polluted shallow wells. During the last three and a half years in which Trent water was used, 78.5 per cent. of the notified cases of enteric fever occurred among that half of the population using river water. By the advice of the Medical Officer of Health, a fresh supply of pure water was obtained from the new red sandstone at Edingley. The amount of typhoid fever suddenly decreased with the introduction of the new water supply, as is shown in the following table, and it has since remained very low. There is no other circumstance known which could have produced this effect, and we have either a marvellous coincidence or a proof that the use of polluted waters may cause a high incidence of typhoid fever without serious epidemic outbursts. This is an exceedingly important subject, well worthy of further investigation, and, in connection therewith, the history of the prevalence of this fever within the metropolitan area is instructive.

In London many cases of typhoid fever occur annually the source of which cannot be traced, and in the report by Dr. Shirley Murphy, Medical Officer of Health, for the year 1894, the distribution of these cases and their relation to periods of flood, etc., is discussed. He says: "The distribution of cases of enteric fever throughout the year was characterised by an increase of prevalence in the 49th, 50th, and 51st weeks. Previous experience of the distribution of cases of this disease in London during the period 1890-3 shows that this behaviour of the disease in 1894 was exceptional, and further inquiry shows that the increase was not due to any special local prevalence, but was manifested over a large area of the county. . . . Study

NEWARK URBAN DISTRICT.

TABLE SHOWING THE CASES OF TYPHOID FEVER NOTIFIED TO NEWARK URBAN DISTRICT COUNCIL, DURING THE YEARS 1890-1899.

	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL.	REMARKS.
1890	1	4	1	2	3	3	3	1	1	6	20	8	53	
1891	25	17	8	5	5	0	12	7	14	12	15	5	125	
1892	1	1	0	5	1	3	5	12	12	7	12	10	69	
1893	16	16	4	5	4	5	5*	8	5	4	4	2	78	
1894	1	0	0	0	0	0	0	2	1	2	3	1	10	
1895	1	0	0	0	0	1	0	0	1	1	3	1	8	
1896	1	0	1	0	0	1	1	0	2	1	0	0	7	Two others imported to the Hospital.
1897	0	0	0	0	1	2	0	1	2	1 *a*	1	1 *a*	7	These two, *a*, were imported.
1898	0	0	1	0	1	0	2	0	1	0	2	0	7	
1899	0	0	0	0	0	0	4	0	3	1	0	0	8	One other imported to Hospital.

* New Water Supply introduced.

CHARLES WILLS, Medical Officer of Health.

of the results of chemical examination of the waters supplied by the London water companies, and which are published by these companies, shows an intimate relation between the condition of the waters as supplied and the condition as to flood of the rivers from which these waters are derived. Certain notable floods in November materially altered the condition of the waters supplied, at a time when there is reason to suppose that some new factor in the causation of enteric fever in London must have come into operation. Inquiry as to the behaviour of enteric fever in populations in the vicinity of the county gives indication of some difference of behaviour of this disease in the population supplied by water from the Thames and Lea, and in the population otherwise supplied, the population supplied from these rivers experiencing an increase of disease in the 49th, 50th, and 51st weeks, corresponding with that experienced in London.

"The hypothesis of water-borne contagion appears better able than any other to afford explanation of the increase of disease in the weeks in question."

During recent years quite a number of limited outbreaks of typhoid fever have been more or less definitely traced to the use of milk which had been stored in vessels rinsed with sewage-polluted water; and in some instances this water was proved to be specifically infected.

The evidence given is sufficient to prove that specifically polluted water, whether derived from a well, spring, or river, can provoke an epidemic amongst the consumers of such water; and it is exceedingly probable that in those outbreaks due to water in which specific contamination was not proved, that such pollution had actually taken place, though the investigator failed to discover it. This is not to be wondered at when we consider the exceedingly mild character of some typhoid attacks. It is not at all uncommon for labourers suffering from such slight attacks to continue their usual occupations; and the discharges

had the water sent to them, both died of the disease after drinking it. In one particular street of 14 houses the only 4 which escaped without a death were those in which this water was never drunk. In a factory employing 200 people, where the water was used, 18 persons died; whereas in the adjoining brewery, where the men never drank the water, no case occurred. Adjacent to these was a block of lodging-houses, supplied with water from the pump, and here there were 7 fatal cases. Certain exceptional cases occurred, of immunity amongst those drinking the water, and of attack amongst those not using it, which rendered the evidence not quite conclusive.

The Rivers Pollution Commissioners in their Sixth Report describe a number of outbreaks in London and elsewhere, in which grave suspicion rested upon the water supply as the cause. In London, during the 1849 epidemic, it was proved that amongst the consumers of Thames water the mortality increased with the increased pollution of the river at the various points from which the water was abstracted. Thus, amongst those using water taken from the river above Kew, the mortality was .8 per 1,000, whilst amongst those drinking water drawn between Battersea and Waterloo Bridge it was 16.3 per 1,000. In 1854 a similar coincidence was observed. In 1866 the area chiefly affected by cholera was almost exactly that of the District supplied by the East London Water Company, which distributed water described as being "unfiltered and excessively polluted with sewage," and which there were grave reasons for suspecting had been specifically contaminated with the excrement of two patients who had died of cholera. They also show that the introduction of pure water supplies had reduced the cholera mortality in the towns which had been attacked by successive epidemics. In the following table the total number of deaths given show the decrease in the mortality after the introduction of pure water supplies, although in each case the population had increased rapidly.

	Year of Cholera Epidemic.			
	1832	1840	1854	1866
Total deaths in Manchester and Salford	890	1,115	50 *	88 *
Total do. in Glasgow	2,842	3,772	3,886	68 *
Total do. in Paisley and Charleston	Not known	182	173	7 *
Total do. in Hamilton	63	251	44	2 *

The most interesting of the localised outbreaks recorded is one which occurred at Theydon Bois, in Essex, in 1865. A gentleman and his wife who had been visiting at Weymouth returned home *viâ* Southampton, cholera having appeared in the latter town eight days before. The gentleman had had an attack of diarrhœa thirty-six hours before leaving Weymouth, and had not quite recovered on his return home. The day after their return the wife was attacked with diarrhœa, and both used the water-closet, the soil pipe of which was afterwards found to be defective. The matters which escaped from the soil pipe penetrated downwards along the outer wall of the house, passed beneath the foundations, and saturated the earth in the immediate vicinity of the well. Water poured down the closet was seen to commence dripping into the well within ten minutes. This water was used by the family, and within twelve days of the specific pollution, out of the twelve persons who drank the water, nine were attacked with cholera of so malignant a type that all the cases proved fatal.

A number of instances have been reported from India and elsewhere, in which polluted water appears to have been the cause of localised outbreaks. At a jail near

* Indicates that prior to this outbreak the town had substituted a pure water supply for an impure one.

difference is all the more important as the water of Hamburg is taken from a place where the Elbe is relatively but little contaminated; but Altona resorts to the water of the Elbe after it has received all the liquid and fæcal refuse of 800,000 people. Under these conditions there is no other explanation for the scientific thinker but that the difference in the incidence of the cholera on these two populations was governed by the differences in the water supply, and that Altona was protected against the cholera by the filtration of the water of the Elbe."

At a later date, however, a small outbreak of cholera did occur in Altona; but Koch was able to prove that at this time the Altona filters were defective and allowed the infectious matter contained in the Elbe water to pass through. The "Comma" bacillus had been found in the Elbe water; it was not discovered in the imperfectly-filtered water, but Koch attributed this to the small quantity of water submitted to examination.

Since the discovery by Koch of the "Comma" bacillus, which he and most other observers consider to be the specific cause of cholera, great attention has been given in India and elsewhere to the detection of this organism in drinking waters suspected of producing the disease. The search so far has been very rarely successful, and at the present time the proof that cholera can be disseminated by drinking water rests upon the accumulation of evidence of cases, such as the above, each failing in some point as an absolute demonstration, but, taken collectively, furnishing proof of a most convincing character.

Yellow Fever.—There is little or no evidence of this disease being disseminated by polluted water. Epidemics which have occurred on board ship have been attributed to the decomposition of the organic matters in the bilge water, and it has been pointed out that when yellow fever was epidemic in Gibraltar, the drinking water was very impure;

but the relationship between the contaminated water and the fever is merely conjectural.

Oriental Boils.—In Syria and other countries, where this disease is prevalent, there is a general opinion that it is caused by drinking certain waters. Various mineral substances have been suspected, but there appears to be very little ground for the suspicion. Many Anglo-Indian authorities think that some parasite may be present in such waters and enter the skin when the water is used for purposes of ablution. Other forms of boils, ulcers, and the elephantiasis of the Arabs, have been attributed to impure waters, but the evidence is too slight to render it worthy of consideration.

Diseases due to Animal Parasites.

The study of the life history of many entozoa has proved that certain stages of their existence are passed in water; hence it at least seems probable that such species as infect man and animals may be introduced with the drinking water, or may gain entrance through the skin when water infested with these organisms is used for washing purposes or for bathing. There is a constantly increasing amount of evidence in support of these theories, which, if correct, furnish additional proof of the risk incurred in drinking impure water, especially in an unfiltered condition. The danger of introducing the ova or larvæ of these parasites into the system is one which can be more easily guarded against than the introduction of the infinitely more minute micro-organisms producing cholera and typhoid fever, since the simplest filtration will remove the former, whilst the most careful filtration can scarcely be trusted to remove the latter.

Bacteria also may multiply indefinitely within the body, however few the number originally introduced; but the number of immature or mature forms of an entozoon which

develop will depend upon the number of parasites which have gained access to the system. In the first case the effect upon the individual will be practically uninfluenced by the number of organisms swallowed, whilst in the second the effect will entirely depend upon and be in direct relation to the number introduced.

The entozoa most likely to infect man through the medium of drinking water are:—*Bilharzia hæmatobia*, *Filaria sanguinis hominis*, *Dracunculus mediensis*, and *Rhabdonema intestinale*, but it is quite possible that *Filaria loa* and many others also gain access to the system in this way.

Bilharzia hæmatobia.—This entozoon is the cause of the endemic hæmaturia so common in Egypt, Abyssinia, and the Cape of Good Hope. The ova are passed with the urine, find their way into water, and hatch into ciliated embryos. These probably pass through a further stage of development in some mollusc or arthropod, again enter the water, and are once more ready to complete the cycle of their life history if received into the body of the human host. Dr. Sonsino, from his experience in Egypt, believes that, were a rule made of filtering all drinking water, no person would become infested with this parasite. He found the disease almost entirely limited to the more ignorant portion of the population who use unfiltered water. A closely-allied organism, believed to be the cause of a peculiar form of hæmoptysis in Japan and the East, may also, judging from analogy, gain access to the system through the same medium--impure water.

Filaria sanguinis hominis.—Mosquitoes derive the embryos of this entozoon from the blood of infected persons (Manson), and the larvæ develop in the body of that insect. These are transferred to water, and thence again into the human body, either, as Manson conjectures, by piercing the skin, or, as is more generally believed, by being swallowed either with the drinking water or accidentally whilst

bathing. This organism, which produces endemic hæmaturia and chyluria, occurs almost exclusively within the tropics, but affects all races and nationalities.

Dracunculus mediensis or *Filaria dracunculus*.—The embryo of this species is aquatic in habit, and according to Fedschenko it undergoes a further development in the body of a cyclops. In some parts of India and Africa it is said, at times, to infect nearly half the population. The abscesses to which the fully-developed worm gives rise being most commonly found in the feet and legs, and especially about the heel, it has been generally assumed that the parasite enters through the skin, to which it may become attached when bathing, paddling, or walking barefooted over moist ground. Hirsch, however, has collected a mass of evidence proving that infection takes place through the medium of the drinking water. For example, he records an outbreak of dracontiasis in 1849 amongst the members of two trading caravans travelling from Bahia to Janeiro. They encamped near a stream and made use of the water for drinking, although expressly warned of the consequences by the natives. They did not bathe in it. A few months later all the members were affected with guinea worm, except a negro, who was the only one of the party who had not drunk the water.

Rhabdonema intestinale.—Sonsino states that this parasite is not quite so innocuous as is generally supposed. He has seen cases of intense anæmia and of enteritis caused by it, and he is certain that it is taken in with foul drinking water.

Ascarides lumbricoides, or common round worm.—Experiments made to infect man with the eggs of this worm have invariably given negative results, yet it seems probable that one of the ways in which persons become affected is by the introduction of the parasite at some stage of its development with the drinking water. Both in England and elsewhere the excessive prevalence of lumbrici has been

noted over localised areas where the inhabitants resorted to polluted ponds or shallow wells for drinking water.

Trichocephalus dispar, or whip worm.—Half the inhabitants of Paris are said to be infected with this parasite, which, however, is far more common in the tropics than in temperate climes. Leuckart has proved that the eggs passed with the fæces must reach water or some very damp medium before the embryo can develop. If it be now introduced into the stomach with the drinking water, the shell of the egg is dissolved and the embryo liberated.

Anchylostoma duodenale.—This parasite induces extreme anæmia, disorders of the intestinal canal, hæmorrhages, etc., and causes great mortality in Brazil, West Indies, and Egypt. During the construction of the St. Gothard Tunnel a severe outbreak of disease occurred amongst the labourers, who had become infected by this worm. Isolated cases have also been recorded in many parts of Italy, and possibly in other European countries. Part of its life cycle is passed in damp earth, and it has been frequently observed that the disease induced by it is confined almost entirely to the lower classes, and more especially to those who drink water from shallow pools and watercourses.

Tænia echinococcus.—The hydatid stage of this tapeworm occurs in man. The tape-worm itself develops in the intestines of the dog, and the ova passed may easily find their way into water, and by this means be introduced into the human stomach. Hydatid tumours are common in Iceland, parts of Australia, Switzerland, and Southern Germany.

Many other parasites which affect domestic animals are taken in by these animals when drinking excrement-polluted water. Thus *Distoma echinatum* is common in the duck, the *Schlerostoma armatum* or palisade worm causes aneurism in the horse, species of *Uncinaria* cause a form of anæmia in dogs, etc., and all appear to require water or some very moist medium in which to pass through a certain stage in the cycle of their life history.

The Effect upon Animals of drinking Polluted Water.—This has been but little studied, but evidence is accumulating tending to prove that drainage from farmyards is not quite so innocuous as is generally supposed, and that water polluted with such excrement may be a carrier of disease. It would be strange indeed if man alone were injuriously affected by imbibing such impurities. As the relation of the diseases of animals to those of man become better understood, it will probably be found that many specific diseases are common to both, and that the one can, in various ways, infect the other. Dr. Vaughan (Michigan) believes that animals may suffer from true typhoid fever, and that he has succeeded in inducing the disease in dogs and cats. If such be the case, it will explain the outbreaks of this fever amongst travellers in uninhabited regions, who have been compelled to drink water fouled by wild cattle, and may also account for many of the localised outbreaks which from time to time occur, where the most diligent inquiry fails to discover any specific pollution of the suspected water by human agency. In 1878, Dr. Hicks attributed an outbreak of typhoid fever at Hendon to the milk of certain cows who drank sewage-contaminated water (*Lancet*, 1878, vol. ii., p. 830), and since that time other observers have recorded outbreaks which they attributed to the same cause; but whether the milk itself was originally infected or merely became infected by the admixture with specifically polluted water is still open to question. In 1889 Dr. Gooch attributed an outbreak of diphtheritic tonsillitis at Eton College to the use of milk from cows supplied with filthy drinking water (*Brit. Med. Journ.*, 1890, vol. i., p. 474). In other similar cases, however, the milk is believed to have been specifically infected from sores upon the teats, but even here the possibility of the disease, of which the sores on the teats are a symptom, being caused by drinking polluted water must be admitted.

In America, where a considerable amount of attention has

been paid to the dissemination of disease amongst cattle by impure drinking water, many outbreaks of anthrax, hog cholera, glanders, and other diseases have been recorded which competent observers attributed to this cause. On one station the carcase of an animal which had died of anthrax was cast into a tank or pond from which about 1,000 head of cattle were supplied with water. Within a very short time 10 per cent. of these died of anthrax. Some years ago, when wool sorters' disease appeared amongst the operatives at a woollen factory in Yorkshire, a number of cattle grazing in a meadow through which flowed a stream receiving the waste water from the mill, were also attacked. In 1893, many cattle on a farm in South Russia died of anthrax, and the bacilli were found in the water used, derived from a well. Professor P Frankland has shown that under certain conditions the anthrax bacillus forms spores in water, and that these spores retain their vitality for a considerable period. Texan fever, by some pathologists regarded as a form of anthrax, is believed to be spread by the use of water contaminated with the excreta of infected cattle.

Hog cholera, a dysenteric affection, is almost certainly a water-borne disease. The specific organism can live for a considerable time in water and even multiply in it, if sewage-polluted, hence American observers are of opinion that specifically-contaminated streams are the most potent agents in its distribution. Upon a farm, in Iowa, where chicken cholera and hog cholera had been prevalent, the dead animals were thrown into a stream. Shortly after a number of cattle, horses, and sheep drinking from the stream were affected with a disease which invariably proved fatal after an illness of about two days' duration.

Glanders, a specific infectious disease, may be transmitted from animal to animal by the use of a common drinking trough, much as diphtheria is believed to be spread amongst children by the use of common drinking vessels.

That many entozoal diseases, amongst cattle, are propagated by polluted waters can scarcely be doubted, and it is quite possible that actinomycosis may be so caused.

At the present time no one would contend that water fouled by cattle was fit to be used by man for drinking purposes, and probably ere long proofs will be forthcoming that the use of such water by cattle is not only inimical to their health, but also a source of danger to the public generally who consume their milk an flesh.

CHAPTER X.

THE INTERPRETATION OF WATER ANALYSES.

By a chemical analysis the saline constituents of a drinking water may be ascertained and their quantities determined, and the same applies also to any sedimentary matter which the sample contains. Chemical analysis also may tell us of the presence of organic impurity, but, as will be seen in the sequel, it can afford us very little information with regard to its quality, and cannot even accurately measure the quantity. By aid of the microscope the minute forms of animal and vegetable life can be detected and identified, but the most minute forms, the bacteria, require a special search to be made to determine their presence and character.

In the preceding chapters on "The Quality of Potable Waters," and on "Diseases caused by Impure Waters," it has been rendered evident that of the many impurities which drinking water may contain, the organic matter only is a serious source of danger, and that by far the greatest risk is incurred in using waters liable to contain certain living organisms which, when introduced into the system, are capable of producing specific disease. Of the presence or absence of such organisms chemical analysis can give us no information. The presence of dead organic matter may be chemically demonstrated, but inasmuch as the nature of this organic matter, whether poisonous or innocuous, is beyond the power of the analyst to reveal, it is obvious that the results of a mere chemical analysis may often be worth-

less or even misleading. This point cannot be too strongly emphasised, since the popular impression, shared alike by the ignorant and the learned, that a chemist, by performing a few mysterious experiments with a water in his laboratory, can pronounce at once whether it be pure or impure, safe or dangerous, must be dispelled. This opinion has been fostered by analysts who rarely hesitate to pass judgment upon a water from the results of their chemical examination, from the determination of the chlorides, nitrates, phosphates, and ammonia, of the organic carbon and nitrogen, and of the oxygen consumed, or of the ammonia derivable from the organic matter. All these factors are of more or less importance as an index of the degree of pollution, but their real value can in very few cases be assessed without some previous knowledge of the source of the water. The inorganic constituents can easily be determined, and whether, either in quantity or quality, these are objectionable, the chemist can safely express an opinion. Those only, therefore, need further be considered which by their presence tend to throw some light upon the source of the organic matter, contained in greater or less quantity in all waters. These are the chlorides, nitrites, nitrates, ammonia, and phosphates; and inasmuch as their determination is often of importance, the value of each may be discussed.

Chlorides.—In the great majority of instances the only chloride present is chloride of sodium or common salt; occasionally other chlorides, as of magnesium and calcium, may be found in drinking waters, but as these are of trifling significance they can usually be disregarded. Rain water, especially in districts near the sea, always contains a trace of salt. Certain geological formations are rich in salt, and waters obtained therefrom may contain considerable quantities. Urine also contains nearly 1 per cent; hence pollution with sewage will add salt to the water. The effluents from many manufactories, alkali works, mines, etc.,

are also rich in chlorine. From these various sources, therefore, the chlorides found in waters are derived. Where the geological strata contain little or no salt, and there are no manufacturing or mining effluents to pollute the water, the amount of chlorides present may serve roughly as an index of the extent to which it has been contaminated by sewage. In Massachusetts it has been found that the amount of chlorine in the surface waters and streams decreases in amount from the seaboard westward or inland. By the examination of waters from sources removed from all risk of contamination, the normal chlorine for such districts has been determined. "By placing on the map of the State the amount of chlorine * normally present in its unpolluted waters, and then connecting the points of equal amounts, lines of like chlorine contents are obtained, which are called *isochlors*." From the map thus prepared the normal chlorine is found to vary from .45 grain per gallon near the coast to less than .06 in the western part of the State (*Board of Health Report*, 1892). Over any given area, the amount of chlorine in excess of the normal, as above ascertained, can only be due to the influence of the population discharging its sewage thereupon. Assuming that 100 persons per square mile add on an average .03 grain of chlorine per gallon to the water flowing from the area considered, the extent of the contamination can be approximately calculated. It must be remembered, however, that the amount of chlorine present does not necessarily signify present pollution. The organic matter which originally accompanied the salt, and which alone is deleterious, may have undergone complete oxidation and destruction, so that organically the water may be very pure although the amount of chlorine present indicates that at one time it was excessively polluted. This fact detracts very considerably from the importance of the

* 1 part of chloride of sodium equals ·61 part of chlorine.

chlorine determination. It affords some evidence of the previous history of the water, and that is all. In insular countries the estimation of the chlorine is of even less value, since they cannot be mapped out into *isochlors.* Over limited areas, however, the normal chlorine may sometimes be ascertained, and any excess found in samples from that district will be in a measure proportionate to the present or past pollution of the water. For example, in the parish of Writtle (Table III., p. 57), the normal chlorine did not exceed 2.5 grains per gallon, yet in that parish subsoil waters were found containing as much as 14.0 grains per gallon, and that this was due to past and present pollution with sewage was substantiated by the excess of other substances, especially nitrates, which, as we shall see, are also in most cases derived from the same source. Unless this normal chlorine be known, the determination of the chlorides has no value whatever. The variation in the amount of chlorine in pure surface waters from various geological formations is given in Table I. and any excess over the amounts given there would probably point to past or present pollution, and in any case would indicate that further investigation of the source was desirable or necessary. In shallow-well waters, even when pure (Tables III. and IV.), the chlorine varies so greatly in amount that it is only in rare cases, as in the one referred to above, that the determination affords any information of value. In spring waters also it is difficult to decide upon the normal chlorine of any particular formation, but if in any case the amount found exceeds the average, the possibility of sewage pollution must be considered. The same remark applies to deep-well waters (Table VI.). If the source of the water be not known, reliance upon the chlorine estimation may lead to serious error. I have known an analyst of repute, after examining one of our Essex deep-well waters, certify that the large amount of chlorine indicated serious contamination with sewage, whereas the water was almost

absolutely pure, hygienically, containing no organic matter, and no excess of chlorine over that natural to waters from that particular source. In several instances, when examining water from these deep wells, I have found the amount of chlorine *below* the normal and have sometimes been able to prove that this was due to surface water (usually impure) having gained access to the well. In other cases a large excess of chlorides has been traced to the influx of sea water. The possibility of the excess of chlorine being derived from manufactories or mines must also be considered before concluding that the water contains contaminating matter of animal origin, and the fact that wells sunk near the sea shore, and near tidal rivers, may contain an excess of chlorides derived from the infiltration of sea water must not be forgotten.

The quantity of chlorides present in a water may sometimes be so considerable as to raise the question whether such water is suitable for a public supply. Quite recently I have had to give an opinion on this point. A deep boring had been made to obtain, from the Essex chalk, a supply of water for a small town. The bore was 500 feet deep, and the water contained over 70 grains of common salt per gallon. This amount gives a distinctly perceptible flavour to the water, and I expressed the opinion that this quantity was in excess of what should be permissible in a public supply. The Local Government Board supported my view, and a fresh source has had to be found. The District Council made another bore upon a site suggested by me, and at a depth of 130 feet found a much more abundant supply of water containing about half the above amount of salt. From investigations made in connection with the above case I came to the conclusion that more than 50 grains of salt per gallon in a drinking water was objectionable, and that 70 grains should condemn it absolutely. Little, however, is known as to the effect of such a water upon the health of a

community, and the conclusion I arrived at is merely an opinion.

Where the chlorides present include magnesium and calcium chlorides, much less than the above amount should condemn the water as being generally unsuitable for domestic purposes.

Nitrates and Nitrites.—The combined nitrogen found in drinking waters is contained in the organic matter, ammonia (NH_3), nitrites ($M'NO_2$), and nitrates ($M'NO_3$). Traces of all three are found in most samples of rain water (*vide* Chap. II.). Nitrogenous organic matter undergoing putrefaction invariably produces ammonia, and by oxidation this ammonia is converted, by micro-organisms found in all soils, into water and nitric acid, the latter decomposing the carbonates present, and forming nitrates of soda, potash, or lime. The ammonia, however, is not apparently converted directly into nitric acid, but passes through an intermediate stage, a lower oxide of nitrogen, nitrous acid being first formed. This process will be described in greater detail when the purification of water is being discussed. The Rivers Pollution Commissioners found that whilst the organic matters contained in sewage, and therefore of animal origin, yielded abundance of nitrates and nitrites by oxidation (no less than 97 per cent. of the combined nitrogen of London sewage being converted into nitrates by slow percolation through 5 feet of gravelly soil), vegetable matters yielded mere traces of these compounds. Upland surface waters "in contact only with mineral matters, or with the vegetable matter of uncultivated soil, contain, if any, mere traces of nitrogen in the form of nitrates and nitrites; but . . . as soon as the water comes in contact with cultivated land, or is polluted by the drainage from farmyards or human habitations, nitrates in abundance make their appearance." Subsoil waters derive their nitrates in part from the oxidised ammonia of rain water, in part from the slow decay of vegetable matter, and

in part from sewage matters. The amount derived from the two former is almost invariably small. Vegetable matter is not highly nitrogenous, and as a rule decomposes but slowly. Animal matter, on the contrary, decomposes rapidly and yields much ammonia. Nitrates serve for the food of plants, and the active growth of vegetation may remove nearly the whole of these salts from a water. In reservoirs the nitrates decrease gradually as the vegetable organisms increase. The total combined nitrogen therefore in a water may at one time exist in decaying animal and vegetable matter, or in the form of ammonia; at another in the form of nitrites and nitrates, and yet again as a constituent of the protoplasm of living vegetable organisms,—in which latter case it is not in solution, but merely suspended in the water. Whenever organic matter undergoes putrefaction in the absence of air or free oxygen, not only are nitrates not formed, but any nitrates present are decomposed, their oxygen being required for the formation of water and carbonic acid by combination with the carbon and hydrogen of the decomposing substances. The nitrogen appears to be set free, possibly accounting for the excessive amount of that element found in such deep-spring waters as those of Bath, Buxton, and Wildbad. In this way the small amount of nitrates found in most deep-well waters is accounted for. Such being the case, it is evident that even concentrated sewage may undergo such changes as would totally obscure its origin so far as the combined nitrogen is concerned. At first this would be contained chiefly in the dissolved animal impurities; after passing through the surface soil, it would exist chiefly in the nitrates formed by the oxidation of the organic matter, later the nitrates may be decomposed, and the nitrogen liberated, when the water would be almost or entirely free from combined nitrogen. On the other hand, certain deep-well waters, especially in the chalk, contain very considerable amounts of nitrates, which it is difficult to believe are derived from

the oxidation of sewage matters. It has been suggested that these nitrates are derived from fossil remains, or from natural deposits of nitrates, or from vegetable matter; but as no proof of these statements is forthcoming, they must be received with reserve. In the eastern counties the chalk wells yield waters which in some districts are absolutely free from nitrates (S.E. Essex), whilst in other districts (Norfolk) they may contain possibly as much as 1 grain of nitric nitrogen per gallon. The following may be quoted as examples.

	Nitric N. per Gallon.	Depth of Well.	Authorities.
		feet.	
Stratford: Phœnix Works	·00	200	J. C. Thresh.
Wimbledon	·03	200	,,
Chatham Public Supply	·48	490	,,
Southend ,,	·05	900	,,
Witham ,,	·45	600	R.P.C.
Mistley: Tendring Hundred W. W. Co.	·05	160	J. C. Thresh.
Braintree Public Supply	·02	430	T. A. Pooley.
Colchester (Donyland Brewery)	·00	305	J. C. Thresh.
Saffron Walden Public Supply	·95	1000	,,
Norwich	·80	About 400	,,

In none of the above examples is there any possibility of recent sewage contamination.

Notwithstanding these facts the Rivers Pollution Commissioners considered the total combined nitrogen to be an index of previous sewage contamination. They assumed that 100,000 parts of average London sewage contains 10 parts of combined nitrogen in solution. The mean amount of such nitrogen found in a large number of samples of rain waters examined was .032 per 100,000. After deducting this latter amount from the amount of nitrogen in the form of nitrates, nitrites, and ammonia found in 100,000 parts of a potable water, the remainder, if any, they say, "represents

the nitrogen derived from oxidised animal matters, with which the water has been in contact. Thus, a sample of water which contains, in the forms of nitrates, nitrites, and ammonia, .326 parts of nitrogen in 100,000 parts, has obtained .326 – .032 = .294 part of that nitrogen from animal matters. Now, this last amount of combined nitrogen is assumed to be contained in 2,940 parts of average London sewage, and hence such a sample of water is said to exhibit 2,940 parts of previous sewage or animal contamination in 100,000 parts." The Rivers Pollution Commissioners, however, point out that, on the one hand, the nitrates may not indicate the full extent of the previous sewage pollution, since the roots of growing crops take up much of the ammonia, nitrites, and nitrates contained in polluted water, and animal matter which decomposes without access of air destroys nitrates; and, on the other hand, that the nitrates present may indicate 10 per cent. of previous sewage contamination in deep wells and springs, and the risk of using such waters be regarded as nil, providing surface pollution be rigidly excluded. This 10 per cent. of previous sewage contamination corresponds to 1 grain of nitric nitrogen per gallon.

Mr. F. Wallis Stoddart, in an excellent paper on "The Interpretation of the Results of Water Analysis,"* describes a series of experiments in which he passed sewage containing cholera bacilli through a nitrifying bed of coarsely-powdered chalk, and found that although the organic matter in solution was completely nitrified, yet the cholera bacilli or spirilla could be detected in the effluent. From the result of his own observations and experiments, he concludes that natural waters "can at most obtain from one-tenth to two-tenths of a grain of nitrogen as nitrates per gallon from sources other than animal matter," and "that practically the whole of the nitrogen of sewage may

* *Practitioner*, 1893.

be oxidised into nitric acid without materially diminishing the risk involved in drinking it." He urges that whenever the nitrogen as nitrates exceeds half a grain per gallon, it indicates "either dangerous proximity of the well to a source of pollution, or such easy communication with it that the distance separating the two points is no guarantee of purification." In the various tables of analyses given in previous chapters will be found instances of many waters, the source of which I carefully examined, and which were collected and analysed by myself, containing more than this amount of nitric nitrogen; and I am perfectly convinced that these waters are hygienically of the highest class, and can be used without the slightest risk or danger. On the other hand, in Table VII. there will be found analyses of many waters, containing very much less nitrogen as nitrates, which have almost certainly (in most cases the proof was very conclusive) given rise to outbreaks of typhoid fever. If Mr. Stoddart's maximum of .5 be accepted as proof that a water is dangerous, then the public and private water supplies of many of our healthiest districts—districts remarkably free from outbreaks of typhoid fever—must all be considered dangerous. As a matter of fact the amount of nitrates which would condemn a water from one source may be absolutely without significance in water from another, all of which goes to demonstrate, as has been previously stated, that mere chemical analysis is absolutely powerless to prove that any water is of such a quality as to be incapable of producing disease amongst those who drink it.

Nitrites may result from the oxidation of ammonia, or from the reduction of nitrates, and, as they are very easily oxidisable, their presence indicates a condition of instability, of matter undergoing change. Usually this matter is of animal origin and derived from manure or sewage, the ammonia produced by their decomposition being in process of oxidation to nitrates. Where the soil is

not sufficient in quantity, or is defective in quality, the oxidation may be incomplete, and incompletely purified and probably incompletely filtered water is the result. Usually in such cases an excessive amount of ammonia is also present. But though usually, this is not invariably the source of the nitrites and ammonia. Where nitrates are present the nitric acid may be reduced by contact with metals, such as iron or lead, forming the pipes in which the water is conveyed, or lining the upper portion of the well. Where such is the case, a trace of the metal can always be detected in the water. Unless this fact be borne in mind--and it often appears to be overlooked- a good and wholesome water may be classed as dangerous or polluted. Certain organisms also found in water are capable of reducing nitrates to nitrites. Still the presence of nitrites always renders a water suspicious, and their origin should be carefully investigated.

Ammonia.—All rain water contains this compound, as does also melted snow. The first portions of a shower, and the rain collected in the neighbourhood of towns, are richest in ammonia. As an average, .02 grain per gallon, taken by the Rivers Pollution Commissioners, is probably fairly approximate, but the variation is very wide (.2 to .01). In passing over or through the ground the ammonia is rapidly oxidised, and by the time the water reaches a stream or the general body of subsoil water, most of it has disappeared. Rain water stored in covered cisterns, however, usually retains its ammonia for a considerable period. In such waters, therefore, the ammonia, unless excessive, is devoid of significance. Many deep-well waters also contain much ammonia, the origin of which has given rise to a good deal of surmise. The generally accepted theory is that it is due to the reducing action of ferruginous sands on the nitrates present. This may be so in some cases, but my observations lead me to believe that it is often due to the reduction of the nitrates by the metal of the bore tube, pump pipe, and

lining of the well. I was led to this conclusion from the fact that I found the water from one and the same well, at one time quite free from ammonia, and at another containing as much as one part of ammonia per million parts of water. In the water containing ammonia I also found a very faint turbidity, which cleared up on the addition of a little acid, and gave the reactions for iron. The clear, ammonia-free water also, when stored for a time in an iron tube became turbid, and nitrites, ammonia, and iron could be detected in it. Generally, however, the ammonia found in river, spring, and well waters is derived from putrescent animal matter—that is, from manure and sewage; but before this conclusion can be safely drawn, the other possible sources must be excluded. Dr. Brown, in his *Report to the Massachusetts State Board of Health*, 1892, whilst agreeing that imperfect oxidation of sewage matter is generally the source of the ammonia, calls attention to the fact that several waters in the State free from such pollution contain a considerable amount of free ammonia. "They are all associated with iron oxide and the fungus *Crenothrix*." Such waters are found also in many swampy regions, and in wells sunk in ferruginous river silt, and usually become turbid from the formation and deposition of oxide of iron when exposed to the air. The odour of these waters is said to be "often disagreeable from dissolved sulphuretted and carburetted hydrogen."

Phosphates.—Phosphatic minerals are widely distributed in nature, and traces may be dissolved by waters rich in carbonic acid. Albuminous matters, whether of vegetable or animal origin, give rise to phosphates by their decay, hence their presence, especially in what the analyst may conceive to be an excessive amount, has been held to indicate contamination. The difficulty of detecting phosphates, when silica is also present, as is usually the case, the still greater difficulty of estimating the quantity, and the very doubtful value of the information when obtained,

has caused most chemists to ignore their presence. Traces may be found in wholesome waters, and their absence affords no proof that a water is free from pollution, hence the determination is useless.

Organic Matter.—By no known process can either the quantity or quality of the organic matter in water be determined. When a known volume of water is evaporated to dryness, the weight of the residue is that of the inorganic and organic substances contained therein. When this residue is ignited the organic matter is destroyed and volatilised, and the "loss on ignition" has been regarded as approximately expressing the weight of the organic constituents. Such, however, is rarely the case, since carbonic acid may be driven off from the carbonates present, and any nitrates present will be more or less completely reduced. Moreover, some salts retain water so tenaciously that the whole is not driven off at the temperature used for drying, and this moisture is given off when the residue is ignited. For these reasons, chiefly, the "loss on ignition" cannot be depended upon as an index of the amount of organic matter present. But although the total amount of the animal and vegetable substances cannot be determined, the carbon and nitrogen therein can be ascertained by careful chemical analysis. Not only so, but the authors of the original process believed that, with certain reservations, the proportion of the nitrogen to carbon indicated whether the organic material was derived from the animal or vegetable kingdom. In fresh peaty water the Rivers Pollution Commissioners found that $N:C=1:11.93$, whilst in similar waters, which had been stored for weeks or months in lakes, $N:C=1:5.92$. After such water had been filtered through porous strata, $N:C=1:3.26$. In fresh sewage the average of a large number of samples gave $N:C=1:2.1$. Highly polluted well waters, soakage from cesspools, etc., gave $N:C=1:3.126$. In sewage after filtration through soil the proportion of N

to C rose from 1:1.8 to from 1:4.9 to 1:7.7. Evidently therefore the ratios of N to C "in soluble, vegetable, and animal organic matters vary in opposite directions during oxidation,—a fact which renders more difficult the decision as to whether the organic matter present in any given sample of water is of animal or vegetable origin."

All nitrogenous organic matter, whether of vegetable or animal origin, yields more or less ammonia when boiled with a strongly alkaline solution of permanganate of potash, and the ammonia so yielded by potable waters is called "albuminoid," or "organic" ammonia. The proportion of nitrogen in the ammonia so yielded to the total nitrogen in the organic matter is unfortunately not constant; but the chemists to the Massachusetts Board of Health believe that when the process is performed as in their practice, about one-half the nitrogen is converted into ammonia. Albuminoid substances of animal origin contain about 16 per cent. of nitrogen, but vegetable matters contain very much less; hence the amount of "albuminoid" ammonia is no index to the amount of organic matter present in the water. Professor Wanklyn, who devised this process, considers that undeniably contaminated waters always yield an excessive amount of albuminoid ammonia (over .10 part per million); usually with much free ammonia (over .08 part per million). If the albuminoid ammonia distils over very slowly and is in excess, but the water contains little free ammonia and very small quantities of chlorides, Professor Wanklyn considers this an indication that the contaminating matter is of vegetable origin. He adds: "The analytical characters, as brought out by the ammonia process, are very distinctive of good and bad waters, and are quite unmistakable." The generally accepted opinion, however, is that no reliance can be placed upon these determinations taken alone, and in the *Massachusetts State Board of Health Report* for 1890 there is quoted as an example the results of the analyses

of certain of the Boston water supplies. Reservoir No. 4 is known to contain the purest water, but the average "albuminoid" ammonia during two years was .26 per million. The water of the Mystic Lake is the worst of the Boston waters, since it contains both sewage and manufacturing refuse; yet during the same period the average albuminoid ammonia was exactly the same as in the purer water. In the table given below many other examples will be found of the erroneous conclusions which may be drawn from a too implicit reliance upon the determination of the ammonia yielded by distillation with alkaline permanganate.

Forschammer devised a process for the estimation of the amount of oxygen required to oxidise the organic matter in water. This method, as improved by the late Dr. Tidy, has become very popular, and many attempts have been made to render the results comparable with those obtained by Frankland's process, in which the amount of organic carbon and nitrogen is ascertained by combustion, but with only partial success. The results, when compared with those obtained by the "albuminoid ammonia" process, show no constant relation between the amount of ammonia yielded by a water when distilled with an alkaline solution of permanganate of potash, and the amount of oxygen absorbed when the same water is digested with an acid solution of the same salt. This process tells us little or nothing of the nature of the polluting material; it does not even distinguish between organic matter of vegetable and animal origin, and it affords us no evidence of the amount of such substances present. Certain bodies of mineral origin often found in water (sulphuretted hydrogen, nitrites, the lower oxides of iron, etc.) also absorb oxygen, and unless great care is taken to ascertain the absence of these, or to ascertain the exact amount of oxygen consumed by them if present, serious errors may be introduced. When these corrections are made the oxygen process is

still open to all the objections which have been urged against the albuminoid ammonia process. It may condemn a perfectly harmless water as polluted, and pass as of good quality a water of most dangerous character. The following table was devised by Drs. Tidy and Frankland.

AMOUNT OF OXYGEN ABSORBED BY 1,000,000 PARTS OF WATER.

	Upland Surface Water.	Water other than Upland Surface Water.
Water of great organic purity	Not more than 1·0	Not more than ·5
,, medium purity .	,, 3·0	,, 1·5
,, doubtful purity .	,, 4·0	,, 2·0
Impure water . . .	More than 4·0	More than 2·0

When the quality of a water is considered from the biological side instead of the chemical, the absurdity of dividing waters into classes of pure, medium, doubtful purity, and impure, is obvious. A water containing a poisonous quantity of typhoid bacilli might upon analysis be brought within any of these classes, according to the quantity and quality of the accompanying impurities. In the analyses given below there are instances of waters coming within Tidy's limit of "great organic purity," yet which proved to be capable of causing disease. I have examined many such waters myself, and have also passed many waters as perfectly safe for domestic purposes which a mere reference to the above standards would have condemned as doubtful or impure.

Many other special processes for determining whether a water be safe or dangerous have been devised, but inasmuch as they are rarely used, it may safely be inferred that they possess no advantage over those to which we have already referred.

Whilst no single determination will enable the analyst to certify that a water is free from danger, or that it is so polluted as to be dangerous to health, the determination

of several constituents may enable him to pronounce it to be polluted and dangerous, but will never justify him in certifying that it can be used absolutely without risk. As the freedom from all dangerous polluting material is the information usually sought from the analyst, it follows that if this cannot be ascertained by analysis, a chemical examination is in most cases quite useless. Where a water is known to be contaminated with sewage, or known to be liable to such pollution, an analysis is superfluous. When we also consider that many sources of supply are only subject to intermittent pollution, and that waters from the same reservoir or from the same well (*vide* Analyses Nos. 24, 25, and 26, 27) may vary considerably in composition, according to the depth from which the samples are taken, the character of the season, etc., it is obvious that the chemical examination of a water is a matter of comparatively trifling importance compared with the thorough examination of its source and an accurate knowledge of its history. Frequently waters are sent for analysis, and the analyst is wilfully kept in ignorance of their origin lest the information should prejudice his report, yet without this knowledge he is not justified in expressing an opinion whether any water can be used with safety. In commenting upon a recent paper in which I expressed these views, a writer in the *Chemist and Druggist* says: "It would seem, therefore, that we are face to face with the question, 'Is water analysis a failure?' It has been so exclusively the province of chemical analysts to pronounce judgment upon domestic waters, and they generally have given so little attention to the large issues attached to analysis, and so very much to sets of standard figures for chlorine, nitrogen, hardness, and so on, that the attack from the medical health side is not unexpected. There has been more wrangling over water analyses than over anything else in chemistry—and for what? Some figure in the second or third place of decimals, probably,

and in regard to what this ammonia or that ammonia implies, when a visit to the source of the water, and an inspection of the sewage trickling into it might settle everything. That is what Sir George Buchanan and Dr. Thresh advocate." The Royal Commission on Metropolitan Water Supply received evidence proving that waters containing very large amounts of organic matter were drunk continuously by a population with perfect impunity, whilst other waters containing so little organic matter as almost to defy chemical detection had proved, time after time, to be of the most poisonous character. For these reasons they conclude that the water question has passed from the domain of chemistry into that of biology. This, however, is not strictly correct. The biological problems involved in the investigation of water supplies are numerous and complex, and as yet but imperfectly understood.

Although a mere analysis cannot guarantee us purity and safety, yet it very frequently can reveal to us impurity and risk. When the source of a water, upon most careful examination by an expert, is found to be free from all danger of pollution, and the chemical examination proves that the inorganic constituents are unobjectionable both in quantity and quality, and that organic matter is absent or present in barely appreciable amount, then safety, so far as human foresight can be trusted, may be guaranteed. If organic matter be present in appreciable quantity—that is, if the water yield such a quantity of organic nitrogen and carbon, or albuminoid ammonia, or requires such an amount of permanganate for oxidation as to render it of suspicious or of doubtful purity—a study of the history of the water and of its geological source may, and generally does, enable an opinion to be formed as to the nature of the organic matter, and as to whether it is of an innocuous or dangerous character. Chemical analysis, therefore, has its use; it is only when it is made the sole arbiter between safety and risk that it is abused, and is

TABLE VII.

RESULTS OF ANALYSES.

NUMBER.	APPEARANCE, ETC.	Results in Grains per Gallon.								In Parts per Million.			
		Total Solids.	Effect of Ignition.	Nitric Nitrogen.	Chlorine.	Temporary Hardness.	Total Hardness.	Organic Carbon.	Organic Nitrogen.	Free Ammonia.	Albuminoid Ammonia.	Nitrites.	Oxygen used in 4 hours.
1.	Turbid and slight weedy odour . .	22·0	...	·014	1·2	...	...	.	...	·13	·30	trace	1·30
2.	Bluish tint, good in colour . . .	37·5	..	·07	1·1	...	31·0	...	...	·09	·07	·0	·0
3.	...	26·0	...	...	1·55	19·9	25·6	..	...	·00	·01	...	...
4.	Turbid . . .	26·4	...	·177	2·23	12·7	30·7	·12	·02	·07	...	...	1·34
5.	,, . . .	26·6	.	·177	2·23	11·2	30·8	·12	·02	·09	...	...	1·29
6.	Colourless and nearly clear . . .	34·4	...	...	2·1	...	...	.	...	·00	·03	...	·13
7.	Pale brown, turbid, peaty taste . .	7·3	...	·00	·49	·0	3·9	·70	·047	·00	...	...	...
8.	Very slightly turbid, peaty taste . .	9·1	...	·00	·56	1·9	6·1	·30	·010	·00	..	...	...
9.	Clear, dark yellow .	10·8	.	00	50			.		02	·12	·0	...
10.	Light brownish yellow	12·0	..		70		.	.	...	01	·12		...

11.	Greenish yellow, clear and bright	10·5	..	·028	·7		.	..	.	·00	·04	...	3·0
12.	Clear, no peaty taste	13·4	...	·036	·84	4·8	8·2	·08	·020	·00	. .	...	...
13.	Brownish yellow, not quite clear	7·2	...	·011	·35	...	...	...	...	·03	·03	...	3·27
14.	Dark brownish yellow, almost opaque	8·54	...	·00	·49	...	.	...	...	·04	·11	...	10·4
15.	...	9·3	...	...	·8	...	...	·354	..	...	...	...	4·16
16.	...	7·7	...	...	·65	...	...	·346	...	...	...	...	4·01
17.	Very pale, brownish	6·2	blackened	trace	·67	1·5	5·0	...	...	·00	·014	·0	·31
18.	Slightly turbid	3·6	...	·025	·16	...	...	..	..	·013	·033	...	...
19.	,,	5·0	. .	·020	·58	...	...	...	...	·002	·020	...	...
20.	,,	2·4	..	·010	·09	...	·8	...	...	·017	·12	...	...
21.	,,	2·8	...	·001	·09	...	·8	...	...	·002	·10	...	...
22.	,,	2·7	...	·004	·16	...	..	...	...	·014	·24	...	...
23.	,,	7·4	...	·04	1·3	...	4·1	...	...	·21	·24	...	...
24.	,,	95·0	slightly charred	·13	25·6	4·0	4·0	...	...	·20	·05	·0	·75
25.	...	113·0	blackened	1·44	14·8	17·0	19·0	...	...	·01	·24	·0	3·25
26.	Slightly turbid and yellow	94·0	brownish	4·14	16·1	13·5	35·0	...	...	·02	·08	·0	1·75
27.	Turbid and yellow	119·0	charred	4·33	22·0	17·3	45·5	...	..	·02	·12	trace	2·50
28.	...	41·9	.	·00	12·7	...	...	...	...	·20	·09	·0	·43
29.	...	45·4	...	trace	6·4	...	...	.	...	·29	·23	·0	·33
30.	...	45·1	...	·00	11·4	...	.	...	...	·22	·10	·0	·35
31.	...	...	..	·06	29·7	...	6·5	...	...	·40	...	...	...

liable to lead to errors fraught with most disastrous consequences. Let the analysis be as careful and complete as possible, but let the results always be interpreted in the light afforded by a searching examination of the source of the sample. Let all so-called standards be abandoned as absurd, and let the opinion as to whether a water is dangerous or safe be based upon a full consideration of other and more important factors.

In the foregoing table the erroneous conclusions which may be deduced from a too great dependence upon analytical data are fully exemplified.

Remarks.

1. Analysis of water from the river Ouse below where it receives the sewage of Buckingham. Examined for the Town Council, 29th February, 1888, by W. W. Fisher, Public Analyst. Report—" Does not appear from the analysis to contain sewage matters." Quoted by Dr. Parsons in his report to Local Government Board on an outbreak of enteric fever in 1888, as a " further illustration of the inability of a chemist to prove the quality of organic matter in water when its quantity is small."
2. Analysis of the Buckingham public water supply by Mr. Fisher. Certified by him to be a first-class water, yet believed by Dr. Parsons to have been the cause of the above outbreak.
3. Analysis of the Beverley water supply from borings in the chalk, by Mr. Baynes, 18th July, 1884. In 1884 an outbreak of typhoid fever occurred here, and was investigated for the Local Government Board by Dr. Page. The evidence led him to conclude that the specific contamination of the water supply was the immediate cause of the outbreak. The water had been repeatedly analysed,

and the analysis given was made "on the very border of the period when the water was acting as the epidemic agent." It was certified to be "of a very high degree of purity, and eminently suitable for drinking and domestic purposes." Specifically infected sewage from an asylum had been spread upon land near the well and reservoir.

4, 5. Analyses of water from the much polluted Trent at (4) Torksey, and (5) Knaith, by Dr. Tidy, 20th December, 1890. The analyst reported that "there is no evidence of the product of sewage contamination." From Dr. Bruce Low's Report to the Local Government Board, on the occurrence of enteric fever amongst the population using the Trent water, 1893.

6. Analysis of the well water supplying Houghton-le-Spring, 24th April, 1889. Early in the month a sudden outbreak of typhoid fever occurred here, and a sample of the water was at once sent for analysis. The analyst reported: "This water is very free from indication of organic impurity. . . . It is a good water for drinking purposes." Dr. Page, who investigated this outbreak for the Local Government Board, found that sewage from a farm three-quarters of a mile away was discharging into the well at a point 45 feet from the surface.

7-14 form a very interesting series of analyses by chemists of the highest repute, of the Tees water as supplied to the towns in the Tees valley. Two outbreaks of enteric fever occurred in these towns, the first between 7th September and 18th October, 1890; and the second between 28th December, 1890, and 7th February, 1891. Dr. Barry reported upon them to the Local Government Board. He found the river above the intake of the Water Companies excessively polluted by sewage, cesspool drainage,

etc. It is with reference to the relation of this water to the typhoid epidemics that Dr. Thorne says: "Seldom, if ever, has the proof of the relation of the use of the water so befouled to wholesale occurrence of typhoid fever been more obvious or patent." The analyses now quoted were made before, during, and after the epidemic periods, yet, as will be seen, in not a single instance did the chemical examination indicate either pollution or danger.

7. Analysis of the Middlesborough water supply by Dr. Frankland, F.R.S., 23rd August, 1890. Report—"Peaty . . . but in all other respects the water is of excellent quality for domestic use, *and it is free from any trace of sewage contamination.*"
8. Ditto., 23rd October, 1890. Report—"With the exception of a peaty taste, it is in all respects of excellent quality for dietetic and all other domestic purposes."
9. Analysis of the Middlesborough water supply by A. H. Allen, F.I.C., 27th October, 1890. Report—The results "negative any suspicion of contamination by sewage or cesspool drainage. . . . No suspicious results were obtained on bacteriological and other microscopical examination."
10. Analysis of the Middlesborough water supply by Messrs. Pattinson and Stead, 29th October, 1890. Report—"Perfectly wholesome and free from any sewage contamination. . . . The microscope reveals nothing of an objectionable character."
11. Analysis of the Darlington water supply by F. K. Stock, County Analyst, 2nd December, 1890. Report—"I have no hesitation in saying that the Tees water, as at present being supplied to consumers, is of good and wholesome quality."
12. Analysis of the Middlesborough water supply by Dr.

Frankland, F.R.S., 1st January, 1891. Report—"Of excellent quality for dietetic and all domestic purposes."

13. Analysis of Darlington water supply by F. K. Stock, County Analyst, 9th February, 1891. "I am of opinion that Tees water, as supplied to the town on 29th January, 1891 (the date when the sample was taken), was good and wholesome drinking water."

14. Analysis of the Stockton water supply by A. C. Wilson, Borough Analyst, August, 1891. Report—"Heavily charged with organic matter of vegetable origin; there is, however, no appearance of animal pollution."

That the river Tees some miles above the Company's intake is grossly polluted with sewage, no one has denied, yet these waters, upon analysis, were said to be pure and wholesome, and free from any trace of sewage contamination. As they are stated by the most competent authorities to have been the cause of the extensive epidemics of typhoid fever, most of them must have been absolutely poisonous at the time they were examined.

15, 16. In 1887, when an inquiry was being held to investigate the pollution of the river Tees, the late Professor Tidy examined a number of samples of water therefrom. No 15 is the mean of several analyses of samples taken above where the river receives the sewage of Barnard Castle, and No. 14 is the mean of several analyses of samples taken at Darlington, 15 miles below Barnard Castle. Notwithstanding the sewage poured in at this town, and at points nearer Darlington, Dr. Tidy reported that the water at the latter place was rather better than at the former, and was good and wholesome. He adds: "I am of opinion that if the quantity of

sewage discharged into the river at Barnard Castle was enormously greater than at present, the self-purifying action of the water would be amply sufficient to oxidise every trace of sewage impurity within a short distance of the outfall. Further, I am of opinion that Darlington would not be prejudiced (although the river is the source of the water supply) even if an outbreak of fever or cholera were to occur at Barnard Castle."

17. Mean of four analyses of the Mountain Ash water supply (spring and surface water) by Dr. Dupré, November, 1887. A serious outbreak of typhoid fever occurred here, commencing in July, 1887, and continuing until October. Mr. John Spear investigated it for the Local Government Board, and attributed the epidemic to insuction of filth into one of the water mains during intermission of the service. Dr. Dupré found the samples almost identical from a chemical point of view, and very pure and free from any indication of sewage pollution. The two samples, however, which were taken from the taps, after six hours' intermission, were found, when examined *microscopically*, to contain fungoid growths and large animalculæ which were absent from the two other samples.

18-23 are analyses quoted from the *Reports of the Massachusetts State Board of Health*, 1890-92.

18. A sample of unpolluted surface water containing less nitrates and yielding more albuminoid ammonia than (19), a sample of surface water known to be polluted by sewage.

20. The average of a series of monthly examinations of the water of the Merrimac River, supplying the town of Lowell during 1891, when typhoid fever was epidemic, and attributed to the water being specifically infected nine miles above the intake.

21. Analysis of water from the Chicopee River supplying the city of Chicopee. Specific pollution is believed to have taken place seven miles above the intake, and to have caused an outbreak of typhoid fever in the city.

22. Analysis of the water from No. 4 reservoir, the purest of the four water supplies to the city of Boston, and (23) of the water from Mystic Lake, the most impure supply, showing that the albuminoid ammonia yielded by the latter does not exceed that yielded by the former.

24. 25 are waters from a deep well in Essex; (24) collected during dry weather; (25) collected eighteen hours after very heavy rain. This well water is liable to most serious pollution, yet a report based merely upon the results of the first analysis would most certainly have been favourable.

26, 27 are waters taken by me from the same well; 26 from near the surface, and 27 from near the bottom.

28, 29, 30. Analyses of waters from bored wells in the chalk supplying the Suffolk County Asylum. From a Report by Dr. George Turner on an outbreak of dysentery.

28, 29. These samples were taken from the same well (350 feet deep), the first on 11th October, 1893, and the other ten days later. The difference in the amount of chlorine is most marked, and led Dr. Turner to conclude that the lining of the bore was defective, admitting subsoil water. Sample 28 corresponds closely with No. 30, which was taken from a second bored well, 305 feet deep, and only 16 feet from the first well. Waters 28 and 30 are probably free from admixture with subsoil water. That such water gained access to the well from which Nos. 28 and 29 were taken was proved by digging a hole near the bore and pouring into it a

quantity of solution of chloride of lithium. Two days later, lithia could be detected in the water pumped from the bore tube. No. 29 is an example of an impure disease-producing water, containing less chlorides and absorbing less oxygen than an unpolluted water from the same source.

31. Upon this meagre analysis this water, derived from a deep boring in the chalk, was condemned, and the analyst said that it could not possibly be derived from the chalk. As a matter of fact the water was exceptionally pure, and typical of the deep chalk waters of the district. Quite a number of instances have come under my observation in which good waters have been condemned as sewage-polluted by analysts who were ignorant of the character of the water derived from particular strata.

With the discovery of the fact that such diseases as typhoid fever and cholera are due to the introduction into the system, not of dead organic matter, but of actual living organisms, faith in the chemical analysis of waters began to be shaken. When still more recently the actual microbes causing these diseases had been identified, and processes were said to have been devised for isolating them from the multitude of other organisms found in water, it seemed as though the examination of water for sanitary purposes had passed from the domain of the chemist to that of the bacteriologist. The study of the number and character of the bacteria, it was hoped, would enable the biologist to definitely pronounce whether a certain water was capable of causing disease, or whether it was perfectly harmless in character. Up to the present time such hopes have not been fully realised, and the results of an ordinary bacteriological examination may be as misleading as those of a chemical analysis. The reason for this is not difficult to explain, when the significance of certain of the dis-

coveries made by bacteriologists is thoroughly understood. An enormous number of species of bacteria have already been discovered, although the science is in its infancy. They are almost ubiquitous, abounding in the air, water, and nearly all articles of food and drink. Of this immense variety very few appear to be capable of causing disease; the remainder are perfectly harmless to human beings, whilst many are already known to discharge most important functions in the economy of nature. Upon their presence the fertility of soil in a great measure depends; they break down the dead organic matter into the simpler forms which can be assimilated by the roots of plants. By their action the foul organic constituents of polluted water are converted into carbonic and nitric acid, which, in combination with the mineral bases form innocuous carbonates and nitrates. They are, in fact, nature's scavengers, consuming the foul and effete, and producing therefrom matters of a harmless character.

The microbes found in water are chiefly bacilli. Micrococci are comparatively rare, whilst spirilla are not uncommon, especially in polluted waters. Already over 200 distinct species of microbes have been discovered in potable waters, and amongst these are several which are pathogenic or disease producing. According to Professor Percy Frankland,* these are—

Typhoid bacillus
Cholera spirillum, or "comma bacillus"
Tetanus bacillus
Anthrax ,,
Tubercle ,,
Bacillus brevis
,, capsulatus
,, proteus fluorescens
,, coli communis

* *Journal of State Medicine*, January, 1894. "The Bacteriological Examination of Water."

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Tubercle ,,
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,, capsulatus
,, proteus fluorescens
,, coli communis

* *Journal of State Medicine*, January, 1894. "The Bacteriological Examination of Water."

Bacillus hydrophilus fuscus
,, pyocyaneus
Staphylococcus pyogenes aureus, and the organisms causing septicæmia in mice and rabbits
(To these must now be added the bacillus enteritidis sporogenes)

Up to the present, however, the only diseases which are certainly caused by drinking specifically-infected water, and the micro-organisms of which have been with certainty discovered in such waters, are cholera and typhoid fever. Doubtless further research will add to this short list, but as yet the organisms causing malaria, dysentery, and other diseases, believed to be produced by specific microbes entering the system with the drinking water, have not been with certainty identified therein. The utmost, therefore, that can be expected of the bacteriologist is that he should discover and identify the cholera or typhoid bacillus, should either of these organisms be present in a sample of water submitted to him for examination, and at least that he should be able to discover such organisms as are more or less characteristic of sewage. The *multitude of other* bacilli present, however, renders the search for one particular organism a difficult and often impossible task; the search has been likened to the finding of a needle in a stack of hay. Whilst, therefore, the absolute identification of the specific cause of cholera or typhoid fever establishes its presence, the failure to isolate it is no proof of its absence. As a matter of fact, numerous samples of water, credited with the production of one or other of these diseases have been examined with negative results. As examples may be quoted the examinations of the water supplies to Hamburg and Altona during the cholera epidemic, and the water supplies to Worthing, and to the towns in the Tees valleys, during the outbreaks of typhoid fever, which recently occurred there. Although the Elbe was known to be polluted with cholera excreta, the comma bacillus was never discovered in the imperfectly-filtered river water,

to the use of which Koch and others, who investigated the outbreaks, attributed their occurrence. At the commencement of the second serious epidemic of typhoid fever at Worthing, two samples of the water were submitted to bacteriological examination by Professor Crookshank. He found that they contained far fewer bacteria than the water supplied to King's College, and that there was a marked absence of liquefying colonies. "There was no colony of typhoid fever bacilli, and no bacillus to which suspicion could be attached of producing typhoid fever." He concluded, from the results of his bacteriological examination, "that both samples of the Worthing water rank as very pure water." Considering that during the construction of additional works in the spring, a fissure was opened which discharged into the wells a large volume of water, polluted by surface drainage, and leakage from defective sewers, and that this mixture of well and surface water thereafter was supplied to the town, and was the water examined by Dr. Crookshank, it is not surprising that the results of these and other examinations were considered by the public as "most remarkable." Chemical examinations made from time to time also failed to detect any pollution. The following statements, made by the Deputy Mayor of Worthing * at a meeting of the Town Council, held 18th July, 1893, are particularly interesting, not only as showing how little reliance can be placed upon either the bacteriological or chemical examination of drinking waters, but also as showing the disastrous results which may follow misplaced confidence in these results. The Deputy Mayor, at the above meeting, after speaking of the finding, about two months ago, of the fissure which gave to the town an enormous additional yield of water, said: "We congratulated ourselves upon that fissure, but

* From Report in the *Sussex Coast Mercury*, 22nd July, 1893. Worthing has a population of about 17,000, and during the year 1893 nearly 1,500 cases of typhoid fever occurred.

I think there is no doubt, and certainly no member of the Sanitary Committee has any doubt, that it is to that very fissure the whole of the difficulty we are sustaining, and have sustained, is entirely due." He then referred to the various chemical and bacteriological analyses which had been made, resulting in the water being pronounced thoroughly good and pure. Notwithstanding these results the Committee cautioned the public that they should boil the water, and the boiling went on until the first outbreak practically ceased. "We were hoping," he said, "that the difficulty had ceased, and that we were to have no more typhoid among us; but, unfortunately, another analysis was made by Dr. Crookshank, the water being taken from two or three different sources, and each sample was declared to be good. Perfectly pure were, I think, the doctor's words. Well now, to that, I am afraid, to some extent, we may attribute the cause of the second outbreak. It was stated publicly, with the best intentions, to allay public excitement and the panic which was prevailing, that the water was perfectly pure, because we had the best evidence that it was so; and I have no doubt that the public, who do not like the trouble of boiling every drop of water they drink, ceased the boiling, and thus the second outbreak came upon us, and is still going on." It is quite unnecessary to point the moral of this plain statement of facts. During the Tees valley epidemic, also, the water was repeatedly examined bacteriologically. Although an excessive number of micro-organisms was found, sufficient in fact to justify the opinion that the water was polluted, the typhoid bacillus was not once discovered.

It has recently been asserted that the so-called typhoid bacillus (Eberth's) is often absent from typhoid stools, and that the *bacillus coli communis*, which is invariably found in all stools, is capable under certain conditions (probably by growth in cesspools and sewers) of acquiring pathogenic properties in man. It is even, by many, believed that

this is either, a degenerate form of Eberth's bacillus, or that it is capable of taking on the same properties, and of causing the same disease—typhoid fever. Such being the case, all waters fæcally polluted may be capable of producing this disease when all the circumstances are favourable, and therefore they must be looked upon with the gravest suspicion, whatever the results of bacteriological or chemical analyses.

All surface waters contain large numbers of micro-organisms, but freshly-drawn deep-well waters, and waters from deep-seated springs, are almost sterile. When such pure waters are kept for a few days, however, the number of micro-organisms increases enormously. Professor P. Frankland says that such a water, containing only, say, 5 microbes per cubic centimetre when freshly drawn, may, even if kept in a sterile flask and protected from aerial contamination, contain, after a few days, perhaps 500,000 in the same volume, or, in other words, as many as are found in slightly diluted sewage. He points out, however, that whilst in sewage the numbers only gradually diminish, in these pure waters "after the rapid increase in numbers follows a correspondingly rapid decline, so that the numbers again very soon fall below those found in impurer surface waters." It follows, therefore, that the purest water which has been kept a few days may be confounded with a water from the filthiest source, and that even if the number of micro-organisms found in a water is to be taken as a criterion of its purity or otherwise, the bacteriological examination must be made before such multiplication can have ensued. In freshly-drawn deep-well and spring waters there should be few or no bacteria; in the purest mountain streams and lakes there should not be more than a few hundreds in a cubic centimetre (15 drops). In ordinary river waters from 1,000 to 100,000 may be found in the same volume, whilst in sewage there may be several millions. Rain, hail, snow, and ice are not free from

bacteria, though usually the number contained therein is small.

Professor Sheridan Delépine, in a recent article in the Journal of State Medicine,* referring to the various modes of examining waters, states that, in his opinion, a bacteriological examination is capable of giving more reliable data than a chemical analysis, especially if the amount of polluting matter is small. He continues: "Our present position with regard to the value and interpretation of bacteriological results will be made clear by a few references to the views held by several authorities.

"Koch (1885) says that the number of micro-organisms in water is of the greatest importance, as it indicates whether or not the water is contaminated with organic matter undergoing decomposition. When decomposing organic matter, which always contains a large number of bacteria, gets mixed with water, this water becomes rich in micro-organisms. Even if one were unable to discover any pathogenic germs in such a contaminated water, the fact that it contains decomposing organic products, among which pathogenic bacteria might be present, is enough to render this water suspicious.

"In his well-known paper on water filtration, Koch, in 1893, has fixed at 100 the maximum number of colonies that may be allowed to be present in 1 c.c. of water properly filtered through sand. Koch admits at the same time that a few of the bacteria which are found in the unfiltered water may pass through the filter and be found in the filtered water. There does not seem to me, therefore, any very good reason for admitting a standard for unfiltered and another standard for filtered water.

"Supposing we admit a numerical standard, we must, if we follow Koch, regard 100 bacteria as the highest number compatible with purity of drinking water.

* Vol. VI., p. 145. "Bacteriological Survey of 'Surface' Water Supplies."

"Miquel (1891) has given a scale of purity, which I give only to show the arbitrary nature of the classification of waters based on numbers only. It must be remembered that the methods used by Miquel reveal a larger number of bacteria than the usual methods:—

Excessively pure water .	0 to 10	per 1 cubic centimetre.
Very pure water . .	10 to 100	,, ,,
Pure water . . .	100 to 1,000	,, ,,
Mediocre (or passable) water	1,000 to 10,000	,, ,,
Impure water . .	10,000 to 100,000	,, ,,
Very impure water .	100,000 and over	,, ,,

"Crookshank gives in 1896 the following scale, equally arbitrary:—

Very pure water may contain up to . . .	100 bacteria to the cubic centimetre.
Water containing . .	1,000 bacteria, or more, should be filtered.
Water containing more than	100,000 bacteria is contaminated with surface water or sewage.

"Macé (1897), after explaining that the mere number of bacteria must be taken only as an indication and not as affording an absolute criterion, gives the following scale of purity:—

Very pure water .	0 to 10	bacteria to the cubic centimetre.
Very good water .	20 to 100	,, ,,
Good water . .	100 to 200	,, ,,
Passable (mediocre) water . . .	200 to 500	,, ,,
Bad water . .	500 to 1,000	,, ,,
Very bad water .	1,000 to 10,000 and over	,, ,,

"Migula (1890) argues that the mere number of the colonies affords us no means of judging of the fitness of water for drinking purposes, but that, on the other hand, a great deal depends on the number of kinds present.

"Good pure spring water from mountains contains only a few species; water which has been contaminated by drainage contains, on the contrary, an exceedingly great number of species.

"Migula holds that there should never be more than ten different species of bacteria in good drinking water. He qualifies this statement by saying that a water containing fewer species may have to be condemned on account of the nature of the bacteria, whilst sometimes a water containing more than ten kinds may be considered fit for drinking purposes.

"As regards the number of colonies, Migula is inclined to admit a maximum of 500, *i.e.*, the limit admitted by most observers. For a time bacteriologists attached a considerable importance to the presence or absence of liquefying bacteria, but I think that as there are several rapidly liquefying bacteria often present, even in unpolluted water, it is necessary to distinguish between those liquefying bacteria which are associated with pollution and those which are not, if the presence of liquefying bacteria is to be used as a criterion at all.

"Meade-Bolton, Lustig, G. Roux, all well known in connection with the bacteriological examination of water, have expressed views similar to but less categorical than those just quoted.

"I need not say more to show that there is, as yet, no consensus of opinion among bacteriologists with regard to the interpretation of the results of water analysis. There is, however, a general tendency to admit that much judgment has to be used in interpreting these results.

"There is no difficulty with regard to very bad waters. Those who propound numerical standards all agree that a water containing 1,000 germs is not good. This in itself is already a very important point gained, for in many suspicious or bad waters which might chemically appear good, the presence of organic impurities can easily be detected

in this way. But when we have to deal with waters containing less than 1,000 bacteria to the cubic centimetre, there is a considerable divergence in the views expressed by various writers."

Professor Delépine adopts a *comparative method* in all his investigations, and says that it has, so far, yielded him results which appear free from ambiguity when applied to the investigation of surface and subsoil waters. He selects waters from sources which by examination are shown to be free from the possibility of pollution, and taking these for his standards compares therewith other waters from the same subsoil, or from other portions of the same collecting surface.

In the Report of the Medical Officer to the Local Government Board (1897-8) there are interesting reports by Drs. Klein and Houston, showing that contaminating matters in waters which, from the chemist's point of view, would be classed as "of high degree of organic purity" can be detected by bacteriological examination, the *bacillus coli* and *bacillus enteritidis* in a water being taken as evidence of its previous sewage contamination. These results I have been able to verify, but occasions have arisen when one or other of these organisms have been found in a water which, from an examination of the source, I could vouch for being "safe." I am not certain, as yet, however, that I have ever met with a "safe" water which contained both these organisms.

In a more recent report (L.G.B. Report 1898-9) these observers state, as the results of the investigations recorded, "that not only is bacteriology capable of detecting, in a water . . . microbes characteristic of sewage, but is capable also of detecting these bacteria when the degree of sewage pollution of the water is *from ten to one hundred times less than* that in which the organic matter contributed by the sewage to the water has failed to get recognition by the methods commonly in use by the chemist."

In another article in the same report by Dr. Houston, it is asserted that the presence of streptococci in any number in a water "is positive evidence of a sort to go far to justify the bacteriologist in condemning a sample of water as unfit for domestic use," since such organisms appear only to be found in water *recently* polluted by sewage. I have, however, found streptococci in "new" wells free from the possibility of pollution.

Koch would regard even filtered river water containing over 100 micro-organisms in a cubic centimetre as open to suspicion; but, as we have just seen, he does not regard such water, if once polluted, as absolutely safe, however careful and thorough the filtration. The Royal Commissioners on Metropolitan Water Supply do not entirely concur with this conclusion. They point out that the typhoid bacillus is, so far as is known, only found in human excrement, and that it has not yet been found to retain its vitality when in fæcal matter for more than 15 days; that in all ordinary waters there exist organisms which "undoubtedly exert an influence in diminishing the vitality of the typhoid bacillus; that exposure to direct sunlight destroys these bacteria; that they have a tendency to subside more or less rapidly in all slowly-moving waters, and to be carried down with other matters held in suspension; and that there are strong grounds for believing that small doses either of cholera or of typhoid poison may be swallowed with impunity. Such being the case, they fall back upon the "evidence of experience," and whilst acknowledging that the various water supplies to London are contaminated with sewage, which may, and often does, contain the specific poison of typhoid fever, and may contain the bacillus of Asiatic cholera, they "state without hesitation, that, as regards the diseases in question, which are the only ones known to be disseminated by water, there is no evidence that the water supplied to the consumers in London by the companies is not perfectly

wholesome." In other words, these polluted river waters, which have undergone a filtration as perfect as that required by Koch (since the freshly filtered London water now, 1900, usually contains less than one hundred micro-organisms in the cubic centimetre), are perfectly safe and wholesome.

In reputedly good waters it has been observed that the micro-organisms present capable of liquefying gelatine by their growth are few in number, whilst in sewage-polluted waters they abound; but this fact is of little value, since it only enables somewhat gross pollution to be detected, and most of these liquefying organisms are perfectly harmless. The attempt to set up a standard of purity based upon the number of micro-organisms in a given quantity is as illogical as the old chemical standards. Both depend upon quantity, whilst the real point at issue is the quality. Bacteriology, like chemistry, may tell us something of hazard and impurity, but the latter certainly cannot be depended upon to determine whether a water is dangerous to health. To condemn one water because it yields a little more albuminoid ammonia than another, or because it contains a few more organisms than another, when we know nothing of the nature of the substance yielding the ammonia, and nothing of the character of the organisms, is obviously so illogical as to be absurd, and yet this is what is almost invariably done. Bacteriological, microscopical, and chemical examinations must always be associated with a thorough investigation of the source of the water, to ascertain the possibility of contamination, continuous or intermittent. Then, and then only, if everything be satisfactory, we may be justified in speaking of safety and of freedom from risk; but where either the bacteriological, microscopical, or chemical examination is unsatisfactory, the inquiry into the history of the water must be most careful and complete, and a guardedly-expressed opinion given only after a full consideration of

the bearing of the one upon the other. The views here advocated are now generally accepted on the Continent. Max Grüber, of Vienna, lays the greatest stress in water examination upon the all-importance of personal inspection of the source of supply. He even believes that in ordinary cases the bacteriological examination can be dispensed with. Flügge considers that the inspection of the source and the arrangements of a water supply carried out with the unaided senses is the most desirable method, and seldom needs to be supplemented by chemico-bacteriological or microscopical investigations. The possibility of accidental pollution is a point too often overlooked; yet it is to such accidental pollution that outbreaks of disease are most frequently attributed, and of this the examination of samples of water, prior to the occurrence of the contamination, may tell us little or nothing. In January, 1897, a very striking illustration of this fact came under my notice.* An outbreak of typhoid fever occurred in a town in Essex, limited to children who had used water from a certain drinking fountain. The water had been submitted to a chemist, who certified that it was all that could be desired and that no suspicion could be attached to it. I was consulted, and upon inquiry found that the water had recently been observed to become turbid after rain. At my request the water was traced to its source. It was found to be conveyed in unjointed earthenware pipes from a spring to a tank supplying the fountain near the foot of the hill. At one point the pipes were crossed by a sewer, the top of which had by some means been crushed in. During heavy rains there was an overflow from the sewer into the water pipes beneath. A little distance above, the sewer received the drainage from a small isolation hospital in which, a few weeks prior to the outbreak, there had been a patient suffering from enteric

* *Vide Journal of State Medicine*, Vol. V., p. 178.

fever. In this case the chemist who examined the water in the first instance said emphatically that the water could not possibly be the cause of the epidemic, as his analysis showed it to be of excellent quality. My analysis of a sample, taken at a later date and after a heavy rain, gave very different results and proved serious pollution.

The danger of such intermittent pollution can rarely be discovered by analysis, since a source yielding under normal conditions a water of great chemical and bacterial purity may be more liable to occasional fouling than a source yielding water containing excessive quantities of chlorides and nitrates, or even of unoxidised organic matter.

CHAPTER XI.

THE POLLUTION OF DRINKING WATER.

In the preceding chapters many illustrations will be found of the ways in which water may become polluted; and in the succeeding chapters frequent reference will have to be made to the subject; yet it appears advisable to consider it here somewhat systematically, since it forms a natural supplement to the two preceding sections. From what has been already said it is evident that by far the most dangerous polluting matters which can gain access to a drinking water are the solid and liquid waste products cast out of the human system and usually deposited in cesspits, cesspools, drains, and sewers. There is a widespread and very erroneous impression that in districts without water-closets the drainage, consisting merely of slop water, is practically innocuous, and that it may be disposed of in ways not admissible with ordinary sewage Chemically and bacteriologically, it is almost impossible to distinguish between the sewage of towns in which water-closets are in general use, and of towns in which other forms of excrement collection and disposal are adopted. In the drainage from the former we have all the chamber slops, the water in which soiled bed-linen, clothing, etc., have been washed; and both these are not only excessively foul, but may also be specifically polluted. Both kinds of sewage, therefore, must always be dangerous; and every effort should be made to prevent their gaining access to any source of water supply.

Pollution of Water at its Source.

(*a*) *Rain and Rain Water.*—Rain water, if collected with ordinary care, is never likely to be polluted with human excrement. It frequently contains the ordure of birds, soot, dust, and decaying vegetable matters, which have accumulated during the dry weather on the collecting area, and all of which are more or less objectionable; but I know of no instance in which the use of such rain water has caused disease (*vide* Chapter II.). These constituents usually render the water so unsightly and unpalatable that no one will use it until after it has been filtered or boiled; and this may account for the absence of any deleterious effects. Such rain water, when kept, appears to undergo some process of fermentation and self-purification, which renders it again bright and fairly palatable. When collected by aid of a "separator," so as to prevent the first washings of the roof or other collecting surface passing into the reservoir or tank, and when properly stored, the rain furnishes probably the safest of all waters for drinking purposes.

(*b*) *Surface and River Waters.*—Water collected from uninhabited moorland or mountainous districts may contain vegetable matter, but will be free from animal pollution. If from cultivated land, manurial matters, more or less changed by oxidation, will gain access to the water. As human excrement is constantly employed as manure, the pollution may be of a dangerous character. In such districts also there must be human habitations, farmyards, etc.; and unless special precautions are taken, the drainage from these will contaminate the water. Cesspits and cesspools are frequently so defectively constructed as to permit of the contents being washed out by heavy rains; or they may overflow into ditches, and the filth be carried into the nearest watercourse. During dry seasons such streams may receive but little polluting matter, whilst in seasons of flood

the accumulated filth of months may be carried into them. In too many instances the whole of the sewage of towns is discharged bodily into rivers which are used a few miles lower down as the water supply to other towns and villages. No doubt in the course of transit from point to point much of the solid matter is deposited on the sides and bottom of the river, and some of the dissolved filth is oxidised or otherwise destroyed; but it is open to question whether any river in this country is sufficiently long for this process of self-purification to be complete, and for the water to become absolutely free from danger. With every flood the deposited filth is disturbed and carried downwards; and unless due provision has been made for tiding over these periods without having to abstract the turbid water, seriously-polluted water may have to be used, and if the filtration be not perfect, serious consequences may ensue. Many outbreaks of typhoid fever have been attributed to the use of such waters. For long periods the consumption of the water may have produced no injurious effects; but an exceptional flood or the failure of a filter bed at a critical period may result in a serious outbreak of disease. Examples of epidemics so produced have already been referred to. No doubt the danger arising from the introduction of sewage into a stream supplying drinking water varies with the proportion of sewage to the volume of water into which it is discharged; but, however small this proportion, it cannot be said that the degree of dilution is sufficient to render the water entirely safe. When sewage has been purified by chemical treatment or by filtration through land, doubtless the danger is reduced to a minimum, but there is always the risk of imperfectly-purified sewage being carried into the stream. Where the sewage is treated by one of the recent bacteriological processes, a still greater degree of purification is attained. If the process be suitably chosen, and effectively carried out, putrefaction of the effluent is prevented, and the

greater portion of the nitrogenous matter is converted into nitrates. Unfortunately, however, there is no evidence that specific pathogenic organisms are removed by such a process. That the effluent from a sewage farm may pollute a drinking water in such a way as to cause disease seems probable from the report on the outbreak of typhoid fever at Beverley already mentioned. It is true that in this case the water contaminated was derived from a well; but had the effluent found its way into a stream used as a water supply, it is not improbable that the result would have been the same (*vide* Chapter XII., on the "Self-purification of Rivers").

(*c*) *Subsoil Water.*—In thinly-populated districts the subsoil water may be absolutely free from any trace of sewage contamination. In populous districts, on the other hand, a considerable amount of sewage must gain access to the subsoil. Fortunately, however, the "living" earth possesses such purifying properties that the filth may be rendered perfectly powerless for evil. In fact, Koch has given it as his opinion that "the subsoil water gives us absolute security with respect to the danger of infection, and it should, therefore, if it can only be obtained in sufficient quantity, and if it is not objected to on account of chemical characteristics, *e.g.*, too great hardness, or too great an admixture of chloride, be preferred under all circumstances to surface water. I indeed hold it even to be desirable, and in some cases even necessary, that works already constructed to filter river water should be so changed as to be used for obtaining subsoil water." As most subsoil waters have received an admixture of sewage, how is it that such a careful observer as Koch can regard it as *under all circumstances* preferable to surface water? The fertility of soil depends upon the presence of organic matter, vegetable or animal, undergoing decay. This decay is almost entirely due to the action of micro-organisms, which produce nitric and carbonic acids, without

the former of which the soil would be practically barren. The decomposition of organic matter appears to take place in three stages. First, ammonia is produced, and this probably by the action of several species of bacteria; next, the ammonia is converted into nitrous acid by an organism discovered simultaneously in 1890 by Frankland and Winogradsky; finally, another organism has been proved by Warrington and Winogradsky to be the cause of the conversion of the nitrous into nitric acid. In rainless districts nitrates accumulate upon the surface, immense deposits being found in Chili, Peru, and various parts of India. In other regions the nitrates so formed are dissolved by the rain and carried to the roots of plants, and serve for their nourishment. The proportion not so utilised by plants as food passes into the subsoil water. All the organisms above referred to are found most abundantly in the first few inches of soil, the numbers decreasing rapidly with the depth, until at a few feet from the surface they are no longer to be detected. Where the surface is covered with vegetation, the decomposition of dead organic matters is so complete, and the amount of nitrate extracted so large, that no undecomposed organic matter and little of the products of its decay reaches the subsoil water. Moreover the undisturbed soil constitutes one of the most perfect of filters; hence subsoil water, if properly collected, is one of the purest of waters, providing the mineral ingredients of the subsoil are not too soluble, or are not of an otherwise objectionable character. In towns and villages where there are aggregations of houses, or even in the proximity to single cottages, the surface soil may be so denuded of vegetation that this process of decomposition may not be complete, and unchanged or only partially changed filth may be washed through into the ground water. Where the filth escapes from defective drains, cesspools, and cesspits, this is still more likely to be the case; hence water obtained from wells in proximity to

such defective sanitary arrangements must be polluted. In towns and villages, especially where such defects are common, the whole of the subsoil water over a large area may be contaminated. Doubtless even here the filtering powers of the earth are most marked, otherwise outbreaks of disease would be much more frequent amongst communities using such water; but the records of every medical officer of health prove that this filtration cannot always be depended upon to remove the germs of disease. A heavy rainfall, either by carrying the filth through with unusual rapidity, or by causing the ground water to rise into the more polluted soil above, may carry these organisms into the wells, and so produce an epidemic. Where wells are improperly constructed and allow of water entering at or near the surface, the danger is greatly accentuated. Where they are open at the ground surface, or where the covering is defective, heavy rains may wash the filth directly into the water. The great difficulty experienced in constructing wells so as to exclude impure surface water leads Koch to conclude that "Wells, constructed no matter how, should not be tolerated in future" (*vide* Chapter IV.). Koch's remarks, therefore, do not apply to ground water as derived from wells of any kind. It must also be remembered that where the subsoil is full of fissures, impurities may be carried along such channels for considerable distances and contaminate the drinking water at a point far from where the polluting matter enters the ground. Thus the epidemic of typhoid fever at New Herrington was proved to be due to the drainage from a farm three-quarters of a mile away from the well, the channel of intercommunication being undoubtedly the fissures in the rock forming the subsoil.

The natural level of water in a shallow well is that of the plane of saturation of the subsoil, A, C (Fig. 13). When the level of the water in the well is lowered by pumping, an area of ground around is drained, the extent of this area

depending upon the porosity of the soil and the depth to which the water is abstracted. The ground drained has the form of an inverted cone, with a rapidly-increasing gradient towards the well, E. The drainage area has been found by experiment to have a radius ranging from 15 to 160 times that of the depression due to pumping; hence polluting matters gaining access to the subsoil within this area will flow into the well. The extent

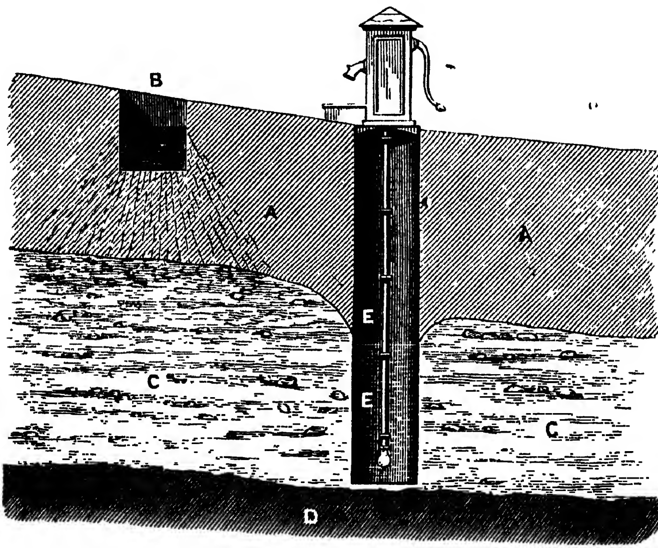

FIG. 13.

of the drainage area varies with the porosity of the soil; where the soil is dense and but slightly pervious the area may not exceed 15 times the depth of the water in the well when at its highest level, whereas where the subsoil is exceedingly porous the area may be 160 times this depth. As in most cases the subsoil water is travelling in a definite direction, if the point of pollution, B, be where the plane of saturation is higher than that around the well, and the

latter is in the line of flow of the subsoil water from where the pollution enters, it is tolerably certain to gain access to the well, either continuously or occasionally, when the level of the ground water rises above a certain height. If the sewage or other polluting matters enter the subsoil at the other side of the well, the risk of contamination is greatly diminished. Hence, in districts where the ground water is polluted locally, the position of the well is of considerable importance.

The prevalence of malarial diseases, enteric fever, and cholera is believed by many sanitarians to be influenced largely by the rise and fall of the ground water. Frequently, in India, outbreaks of malaria have followed a rapid rise in the ground water, due to heavy rainfalls, and the epidemics may have been due to the contamination of the wells by the filth carried down by the rain. Pettenkofer, at Munich, found that enteric fever was most fatal when the subsoil water was lowest, and especially when the fall had been rapid and from an unusual height. Fodor, at Buda-Pesth, found exactly the opposite condition to obtain, the enteric fever mortality rising and falling with the ground water; and this connection between the height of the subsoil water and the prevalence of enteric fever has been observed from time to time in this country. Where this has occurred, the explanation which suggests itself is, that the water had become more and more polluted with the rise in level, and this is the generally-accepted opinion in this country; but there are many eminent observers both here and on the continent who do not accept this explanation. Pettenkofer also regards cholera as a disease, the spread of which is largely influenced by the movements of the subsoil water. Even if such is the case, which is by no means generally admitted, it may be that the effect is due rather to the varying extent to which the water becomes polluted, rather than to the fouling of the ground air by the decomposition of

the organic matter and the active growth of specific organisms in the damp soil left by the falling ground-water.

Baldwin Latham has asserted that at Croydon, which is supplied with water from springs in the chalk, measles, whooping-cough, and diphtheria were more prevalent during wet seasons, when the ground-water level was high, and that typhoid fever and small-pox were liable to become epidemic when heavy rains followed a prolonged drought. Springs fed by subsoil water will be affected in quality in the same way as the water in wells, but only rarely to the same extent. Such springs usually drain considerable areas, and therefore, unless the pollution arises near the source of the spring, the dilution will be great, and during the period which must elapse between the impurity entering the ground and its reaching the outlet, time will have been allowed for a more or less complete oxidation of the organic matter in the pores of the soil, and for a more or less complete filtration to have occurred In rural districts springs are frequently fouled by cattle, and by the rainfall, if heavy, washing filth into the dipping places, since the springs are not properly protected. Land springs, fed by thin beds of sand, or gravel, or light porous soil of any kind, are especially liable to be seriously affected by manure spread upon the surface of the ground, and if this manure contain human excrement the danger is greatly enhanced. In a recent outbreak of typhoid fever which I investigated, and which affected a small group of cottages, I found that the excreta from a mild case of this fever had been discharged into a defective privy cesspit sunk in the porous soil within a few feet of the land spring which supplied the cottages.

When slop water, the contents of earth-closets, etc., are properly disposed of by spreading upon a sufficiently large area of garden or other cultivated ground, the danger of specific pollution of the ground water is reduced to a minimum. Where the sewage escapes from defective drains

at some depth from the surface, and excremental filth oozes through the sides of cesspools and cesspits sunk in the ground, the danger of pollution is considerable, and increases with the proximity of these defects to the point from which the subsoil water is abstracted. The model bye-laws of the Local Government Board require not only that the drains, cesspits, and cesspools shall be so constructed as to prevent any such leakage, but also that the two latter shall not be constructed within a certain distance from "any well, spring, or stream of water used, or likely to be used, by man for drinking or domestic purposes, or for manufacturing drinks for the use of man." Under ordinary circumstances the distance from a privy should be not less than 40 to 50 feet. Cesspools being still more dangerous, the minimum distance from a well should not be less than 60 to 80 feet. Since dust and débris, when being cast into ashpits, may be blown about, and so gain access to a well or stream supplying drinking water, no ashpit should be less than 30 to 40 feet from the water supply. The proper paving of yards, of pig-styes, stables and cowsheds, of slaughter houses, of business premises, especially where offensive trades are carried on, efficient drainage and sewerage, and a proper system of sewage disposal, are all necessary, not only for preventing the pollution of the ground water, but also of the ground air, the condition of the latter being probably as important a factor in determining the salubrity or otherwise of a locality as the condition of the former. The burial of the carcasses of animals near a well may cause pollution of the water, and it is believed that anthrax may be spread amongst cattle by the use of water contaminated by the decomposing bodies of other animals which have died from that disease. The proximity of a graveyard to a source of water supply is certainly undesirable; but if the direction of flow of the ground water be from the well towards the graveyard, danger will only arise when, by

pumping, some of the graves are brought within the drainage area. If the distance from the graves to the well be sufficient to exclude the former from the drainage area of the latter, however heavy and continuous the pumping required for the supply of water, there will be little or no danger of contamination from this source. If, on the other hand, the flow of water be from the graveyard towards the well, or the well be within the drainage area above described, the supply will almost certainly be contaminated. Such waters, and waters from the neighbourhood of battle-fields, have frequently given rise to dysenteric diarrhœa amongst the populations consuming them.

It is well known that the earth around gas mains acquires an offensive and peculiar odour. Where the mains are defective this smell is most marked, and perceptible at a great distance from the pipes. It may even reach the ground water and taint the wells. In 1884 the wells in the Clarence Victualling Yard at Portsmouth had to be closed on account of the impregnation of the water with coal gas which had escaped from the leaky mains traversing the yard. "In Berlin in 1864, out of 940 public wells, 39 were contaminated by admixture with coal gas" (Parkes).

(*d*) *Deep-Well Water.*—The pollution of deep-well water very frequently arises from defects in the construction of the well. If the sides are perfectly impervious and the top properly protected, the access of surface water will be entirely prevented; where these conditions do not obtain the water may become contaminated. As will be seen, when the construction of deep wells is being considered, it is often exceedingly difficult to keep out water from the more superficial water-bearing strata, which may have to be pierced in order to reach the pure water in the rocks below. A striking instance of this fact will be found in the account of the fatal outbreak of dysenteric diarrhœa at the Melton Asylum (Chapter IX.). The water tapped by the deep well may itself be impure, especially if the

water-bearing rock be fissured and the outcrop be in an inhabited district. If the fissures are open or only contain freely-permeable rocky débris, polluting matters may travel considerable distances. In the *Edinburgh Medical Journal* for November, 1894, Dr. A. C. Houston gives an account of a well at Morningside, 294 feet deep, which yielded polluted water. The pollution was apparently due to the discharge of sewage into a quarry 800 feet away, since the pollution ceased soon after the sewage was diverted into the Edinburgh sewers. Several other instances of such pollution have already been referred to.

Pollution of Water arising during Storage.—Reservoirs fed by springs and streams, if not provided with some arrangement for excluding storm water, may be contaminated by filth carried down by the floods. When rivers are in flood, the impurities which had deposited on the bottom and sides, and which may contain the specific organisms of enteric fever, and possibly of cholera and other diseases, are disturbed and become suspended in the water, and if allowed to pass into the storage reservoirs may lead to an outbreak of disease, especially if the filtering arrangements at the time are not in perfect working order. Many extensive epidemics of enteric fever have been attributed to the use of water so polluted. At Ashton-in-Makerfield a recent outbreak of typhoid fever was attributed by Dr. Wheatley, the Local Government Board Inspector, to the pollution of the water in the reservoir by the manuring of the ground immediately surrounding it with the contents of the privies and middens of the town. Surface water from these fields actually drained directly into the reservoir. During the latter half of 1893 an epidemic of typhoid fever occurred in and around Paisley, affecting over 800 people. Dr. Munro, the County Medical Officer, attributed it to the pollution of the water supply, and upon visiting the reservoir a month after the beginning of the epidemic he found that until the 6th of July there had

existed close to the margin of the water an inhabited farm house, "the drainage or soakage from which could only escape into the reservoir." Dr. P. Frankland, who examined the collecting ground and the filter beds, proved that the filters were in an unsatisfactory state. In 1885 an outbreak of typhoid fever occurred in Pennsylvania. 1,200 people were attacked and 150 died. Stampfel states that during the early spring the *dejecta* from a typhoid patient were thrown upon the snow lying on a hill sloping towards the source of the public water supply. A sudden thaw setting in, the impurities would be carried down with the melted snow. This occurred on 25th March, and on 10th April the epidemic commenced. Just at that time the water from this particular source was being used to an unusual extent. Those who derived water from other sources were not affected.

The growth of certain vegetable organisms in open reservoirs may result in the production of odorous substances affecting the whole of the water. These have been already referred to in a preceding chapter. Covered service reservoirs may have an overflow connected with a sewer by means of a trap. If for a lengthened period the water level never rises sufficiently high to reach the overflow, the evaporation of the water in the trap might unseal the latter and allow of sewer air gaining access to the water in the reservoir. Of course the overflow should discharge in the open air and at some little distance from a trapped gully communicating with the sewer. Overflow pipes from house cisterns have frequently been the cause of the contamination of the water stored therein, from being directly connected with soil pipes or drains, and outbreaks of disease have been attributed to the use of such water. House cisterns also are often placed in situations which render the water liable to pollution. Even at the present day it is not uncommon to find such a cistern within a water-closet. Usually they are placed in inaccessible

corners and left uncovered. In a large institution, recently, a series of cases of erysipelas and diphtheria led to the examination of the drainage, water supply, etc. The water drawn from the taps within the buildings was found upon analysis to show signs of pollution, whereas the water from the main before entering the premises was free from suspicion. When the cistern was examined, it was found to contain a considerable amount of filthy-looking sediment and the decomposing bodies of a rat and bird. When the cistern had been thoroughly cleaned the water from the taps was as pure as that from the main. Where the house cistern supplies directly the water used for flushing the closets, there is always a danger of air from the closet pan finding its way into the cistern. All these defects admit of simple remedies. The overflow pipe should terminate in the open air; the water-closet should be flushed from a separate cistern; the house cistern, if it cannot be dispensed with, should be tightly covered, placed in an easily accessible situation, and kept perfectly clean.

The materials of which tanks and cisterns are composed may contaminate the water. New bricks, cement, and mortar give up certain substances to the water stored therein, and if the cement and mortar contain road-scrapings, the dissolved substances may not be of an entirely innocuous character. In rural districts no new house can be inhabited until the owner has obtained from the Sanitary Authority a certificate to the effect that it has within a reasonable distance a wholesome supply of water. In the discharge of my duties I have frequently to examine water from recently-constructed wells, which, from their position and my knowledge of the character of the subsoil of the locality I should regard as of satisfactory quality, yet I often find that such waters are excessively hard, and give indications of the presence of organic impurity. The hardness is due to the salts given up by brickwork, mortar, and cement, whilst the

organic matter is in part derived from the wooden curb at the bottom of the well; but I am strongly inclined to believe that it is in greater part derived from road-scrapings which have been mixed with the bonding and lining material. The water in such wells gradually improves in quality as the soluble matters are exhausted. Tanks made for storing rain water, if lined with cement, may cause the water to be very hard even for a prolonged period. Underground tanks, if not properly constructed and covered, may admit impure surface and subsoil water. Waters of less than 1° of temporary hardness dissolve to a slight extent both lead and zinc, and therefore will act more or less freely upon cisterns lined with these metals. Waters with a temporary hardness of 1° to 3° may at first attack a leaden cistern; but the surface gradually becomes covered with a thin white, opaque deposit, which protects the metal from further action. If the surface be now scoured, the lead is again attacked. Decomposing organic matters and the presence of air are believed to increase the plumbo-solvent action of a water; hence, if stored in a dirty cistern, it may dissolve lead more freely from the sides thereof than from the surface of a clean leaden pipe. Roques,* in a paper on "The Perforation of Zinc Cisterns and the Corrosion of Lead Pipes by Water," states that zinc and galvanised iron cisterns are not corroded uniformly but in well-defined places, which fact he attributes to the galvanic action set up between purer and more alloyed portions of the metal. The presence of nitrogenous matters and ammonia he found to accelerate the action, especially in the case of zinc. The action was also most marked in the presence of oxygen, and at the surface where the metal is alternately in contact with water and air. Waters of over 3° of temporary hardness may with safety be stored in either galvanised iron or

* *Bulletin de la Société Chimique de Paris*, 5th June, 1880.

leaden cisterns. Wooden water-butts are an abomination. Under all circumstances wood is a most unsuitable material of which to construct receptacles for storing water; it gradually rots and gives up organic matter to the water, and encourages the growth of worms and other low forms of life.

Pollution of Water arising during Distribution.—Water, whilst in the mains and service pipes, may be affected in quality either by its action upon the materials of which the pipes are constructed, or by the insuction of gaseous and liquid impurities.

Cast iron is powerfully acted upon by soft waters. Hence, if such waters are distributed through mains of this material, the surface of the pipe becomes corroded, and the water, carrying with it a little of the rust in suspension, becomes more or less turbid and unsightly. The rust which forms being much more voluminous than the iron from which it is produced, forms concretions on the sides of the pipes, gradually decreasing the calibre, until they are no longer capable of conveying a sufficient quantity of water, or until the metal is so decreased in thickness as to be easily perforated or fractured. By using pipes which have been coated inside and out with Angus Smith's varnish (of pitch and coal-tar oil), this corrosive action is almost entirely prevented. The common method of "jointing" water mains has frequently led to the deterioration of the quality of the water. Tow or gaskin is used for caulking the joint, to prevent the molten lead running into the interior of the pipe, and at each joint therefore more or less tow is exposed to the action of the water. In a long main this may impart a peculiar odour and taste to the water, due to the organic matter which it has dissolved. The Rivers Pollution Commissioners in their 6th Report, page 222, state that these hemp-stuffed joints afford a nidus for the breeding, development, and decay of animalculæ; so that the deterioration of the

included, but I only heard of one case of drop-wrist by itself. Lead poisoning is a complaint which may imitate almost any other complaint, and it is a practical point to know that we had it rampant in this district, and doing immense damage to health, without recognising what we were dealing with." Well waters also may be affected by the lead piping attached to the pump. This is especially the case with waters from the Bagshot sands, which appear to contain very little carbonate of lime. In several parts of my districts, where the water is derived from these beds, a trace of lead can be found in all the supplies drawn through a leaden suction pipe. The Rivers Pollution Commissioners mention that some polluted shallow-well waters not only act upon lead violently, but continuously, and that several instances of poisoning from the use of leaden pump pipes had come to their knowledge. The one analysis given of such a water shows that it was far purer than the average of shallow-well waters, but that the temporary hardness was under 1°. When a galvanised iron pipe was substituted for the leaden one, the water, as might have been expected from its composition, became charged with zinc, and zinc poisoning followed the lead poisoning. The so-called tin-lined lead pipes also yield lead to the water, inasmuch as the tin in the process of lining becomes alloyed with the lead.

As previously stated, water which acts upon lead will also attack the zinc coating of galvanised iron. A case of poisoning from this cause recently came under my notice. The water supply to a newly-erected country house was derived from a spring arising at the edge of a patch of Bagshot sand. The water was piped from this spring to the house, a distance of half a mile, through galvanised iron pipes. The only child, who, prior to the removal into the new house, had been perfectly healthy, became a sufferer from obstinate constipation. At length suspicion rested upon the water supply, probably because an

iridescent film always formed on its surface when exposed in open vessels, or when heated in an open pan. (This film is very characteristic of the presence of zinc, and is often put down to a trace of oil or grease.) Upon analysis I found that the water contained about 3 grains of carbonate of zinc per gallon. When the water supply was changed, the constipation ceased. Many months after, I again examined the water, which had been allowed to flow freely through the pipe, in the hope that it would speedily dissolve off the whole of the zinc; but it still contained too large a quantity to be considered safe for domestic use. During the present year (1900) I have found zinc in several samples of water, one of which was suspected to be the cause of an epidemic of diarrhœa. I found, however, that the zinc was only present in the water drawn in the early morning, doubtless taken up whilst standing in the pipes through the night. Dr. Heaton, in the *Chemical News* (22nd Feb., 1884), gives an analysis of a water from near Llanelly, which is carried for half-a-mile through galvanised iron pipe. It was found to contain over 6 grains of carbonate of zinc to the gallon. Unfortunately the degree of temporary hardness is not stated, nor the reason why the Medical Officer sent it for analysis. Dr. Venables, in the *Journal of the American Chemical Society*,* gives the analysis of a spring water which, after passing through 200 yards of galvanised iron pipe, and after being in use a year, contained over 4 grains of zinc carbonate per gallon. The temporary hardness in this case was under 1°. He concludes that, "when the dangerous nature of zinc as a poison is taken into consideration, the use of zinc-coated vessels in connection with water or any food liquid should be avoided." Wooden pipes, which were formerly used for conveying water, are quite unsuited for the purpose, chiefly on account of the

* Reprinted in *Chemical News*, 5th January, 1885.

defective joints. They are also said to rot and contaminate the water, but specimens of such pipes, now in the Hornsey Museum, and which had been in use in London for probably two centuries, show no signs of rotting.

The insuction of polluting matters into water mains, and the danger arising therefrom does not seem to have received the attention it deserves. When the water supply is shut off, as is done periodically where the supply is intermittent, and occasionally, for various reasons, where the supply is constant, it is obvious that little or no water can be drawn from the mains at any point without air or water being drawn in at other points, as at unturned taps, ball hydrants, defects in joints, perforations through pipes, etc. Where water-closets are flushed directly by a tap from the service pipe, should this tap be defective or not turned off, air, and possibly filth may be drawn into the pipe from the closet pan. To an accident of this kind Dr. Buchanan attributed the outbreak of typhoid fever at Caius College, Cambridge. The same medical officer, when investigating the cause of the prevalence of typhoid fever at Croydon in 1875, made a series of experiments of a very interesting character. He was partly led thereto from the recorded incident of bloody water being drawn from a tap at a house next door to a slaughter-house. He put into a closet pan sufficient burnt sugar to colour some thousand gallons of water. This pan was flushed with a stool tap. During the intermission of the water supply the whole of the burnt sugar solution was drawn into the mains, and, strange to say, only from one house was a complaint received of the discoloration of the water. Most of the colouring matter must therefore have travelled a considerable distance along the mains, and have become very largely diluted before reaching the consumers. The balls in ball hydrants fall when the water pressure is reduced in the mains by drawing water after the supply has been turned off at the works. The boxes are usually

placed below the ground level as a protection from frost, and are generally found filled with dirt which has washed in from the roads. Dr. Kelly, who investigated an outbreak of typhoid fever which occurred at West Worthing in 1893, attributed it to the pollution of the water in a certain main by the insuction of filth from these hydrant boxes.* He examined many of these hydrants before the morning pumping had begun, and found most of the balls down, and most of the boxes half full of mud. "It is obvious," he says, "that any surface or road filth may thus enter the mains in wet weather, and a person may drink impure water which has been fouled at a distant point." Where the water mains are defective, the insuction may take place through the apertures in the pipes or joints. Gas, emanations from sewers, foul ground air, and the water which had previously escaped from the main when under pressure, may be drawn into the pipe during the intermission in the supply. Sewage from leaky drains and sewers has in this way gained access to the water mains, and several serious outbreaks of typhoid fever have been attributed to this cause. The serious and continued epidemic of typhoid fever at Mountain Ash (Glamorganshire) in 1887 was attributed by Mr. John Spear, who investigated it, to the pollution of the water in a certain branch main, and the distribution of the disease led him to predict almost the exact spot where the contamination took place. When the main at this point was laid bare it was found to be laid alongside and even through old rubble drains, and the main itself was here defective. He had "opportunities of observing how considerable was the suction of air into the pipes at certain points after intermission of supply, and, on its renewal, how much air,

* Hydrants of this character cannot be too strongly condemned. It was subsequently found that water from the specifically polluted mains supplying Worthing proper had been used for watering the streets in West Worthing.

coming with much noise and force, had to be expelled," proving that during intermissions of the service serious contamination of the water of the special main must have occurred.

Dr. M. A. Adams, F.R.C.S., Medical Officer of Health for the Borough of Maidstone, in his Annual Report for 1894 states that he found in May that the water from a particular hydrant was polluted. Upon investigating the cause, the main was found to be defective at two points near a disused drain. Dr. Adams explains the insuction of foul matters by stating that there was a tendency for this service pipe to empty itself in favour of the lower placed hydrants, and when the taps at these lower places were shut off, a wave of water pressure was sent forward to the higher level; when this wave reached the hydrant implicated, the water recoiled upon itself, and set up a sudden and strong retreating current in the opposite direction, which produced the insuction. He adds, "This seemingly small matter ought not to be lost sight of; it teaches a practical lesson in hydraulics of the greatest sanitary importance."

Where water mains are directly connected with the sewers in order to supply water for flushing purposes, there is always a danger of sewer air gaining access to the mains; hence such a mode of flushing should be discontinued.

Not only is polluting matter drawn into service pipes and mains during intermissions in the supply, but even when the pipes are running full such insuction is possible. Our knowledge of this subject is entirely due to Dr. Buchanan's investigations, made in connection with the Croydon epidemic, previously referred to. He found—"(1) The lateral in-current is freely produced when the water pipe is descending, and when the pipe beyond the hole is unobstructed; (2) If the force of water-flow in a descending pipe be moderate, a moderate degree of obstruction beyond the hole does not prevent the in-current; (3) In horizontal pipes of uniform calibre, when the flow is

strong, or the pipe beyond the hole is long, or when the end of the pipe is at all turned upwards, the in-current does not take place; but (4) Momentary interference with flow *a tergo*, or momentary reduction of obstruction *a fronte*, allows a momentary in-current through the hole; (5) In-current through a lateral hole takes place with incomparably greater ease when the hole is made at a point of constriction of the water pipe."

Potable water may also be contaminated by the barrels, skins, etc., in which it is conveyed, when distributed by these means. Where the supply is not laid on to the houses it is often stored in buckets, open jars, tubs, and other vessels, which may be unsuitable from the difficulty of keeping them clean, or on account of the material of which they are composed. The water in them may also be exposed to foul emanations from drains, closets, accumulations of filth, or to dust from the proximity to ash-places, and so become polluted. In eastern countries many holy wells and pools from which pilgrims drink are defiled by the water being poured over the people and being allowed to run back into the well or pool, or by the pilgrims actually bathing in the water. In these countries also the tanks which contain the drinking water are often used for rinsing clothes and for bathing purposes. Such modes of pollution rarely occur in this country, but people have been known to bathe in reservoirs used for supplying drinking water, and dogs are sometimes drowned therein.

From the multitude of ways in which water may be polluted—at its source, during storage, during its passage through the mains, and within the premises which it supplies—it follows that not only must the utmost care be exercised in the construction of works, and in the distribution of the water, but that this must be supplemented by a vigilant and continuous supervision over every detail, if the purity of the supply is to be kept above suspicion.

was very small, "so minute indeed that, even assuming it to go on at the same rate by night and day, in sunshine and gloom, it would require a flow of 70 miles to destroy the organic matter." To exclude certain elements of uncertainty, diluted London sewage was next experimented with. It was agitated with air and then allowed to syphon in a slender stream from one vessel to another, exposed to light, and falling each time through 3 feet of air. The results indicated approximately the effect of oxidation which would be produced by the flow of a stream containing 10 per cent. of sewage for 96 and 192 miles respectively, at the rate of one mile per hour. By the flow of 96 miles the organic carbon was reduced by 6.4 per cent., and the organic nitrogen by 28.4 per cent., whilst the flow of 192 miles reduced the former 25.1 per cent., and the latter 33.5 per cent. Fresh urine and deep chalk-well water were next mixed together and submitted to similar treatment. Still less effect was produced; the carbon was but slightly reduced, whilst the nitrogen showed an actual increase. Finally, the results were checked by the examination of the gases dissolved in dilute sewage (5 per cent.) after standing for different periods in accurately-stoppered bottles exposed to diffused daylight at a temperature of about 17° C. The dissolved oxygen gradually disappeared, but so slowly that "so far from sewage mixed with twenty times its volume being oxidised during a flow of 10 or 12 miles, scarcely two-thirds of it would be so destroyed in a flow of 168 miles, at the rate of 1 mile per hour, or after the lapse of a week."

Weight of Dissolved Oxygen in 100,000 Parts of Water.	
·946	Immediately after Mixture
·803	After 24 hours
·616	,, 48 ,,
·315	,, 96 ,,
·201	,, 120 ,,
·080	,, 144 ,,
·036	,, 168 ,,

The Commissioners believed that it was the clarification by subsidence which takes place in nearly all rivers, which had led to the belief, so general, but erroneous, in the rapid self-purifying power of running water. Their conclusions, however, were disputed by the late Dr. Tidy and others; but inasmuch as, at this period, the part played by the minute forms of animal and vegetable life in the process of purification was unknown, many of the experiments which they recorded have now little or no interest. One set of observers held, with the Commissioners, that purification where it took place was chiefly due to the deposition of suspended impurities, others contended that much of the dissolved organic matter also disappeared. This latter view was strongly supported by the report of Drs. Brunner and Emmerick (1875) on the river Isar as it flows through Munich. They took every precaution to render the results trustworthy, estimating the quantity and strength of the sewage and other refuse matters entering the river from the city sewers, and making due allowance for the effect of dilution by its tributaries. The results of analyses, inspection, and calculation proved that the river water two hours' flow below Munich was practically as pure as the water above the city, or, in other words, that all the dissolved and suspended impurities cast into it at Munich had disappeared. The former view—viz., that subsidence and dilution are the main factors in producing the so-called self-purification—is still upheld by, amongst others, Professor Percy Frankland. He undertook a series of experiments to test this point in connection with the Thames, taking samples of the water flowing in the river from different points on the same day. One day at Oxford, Reading, Windsor, and Hampton; on another day at Chertsey and Hampton, etc. His analyses of these waters are given in a paper contributed to the International Congress of Hygiene, entitled "The Present State of our Knowledge concerning the Self-Purification of Rivers," and

he concludes, "From the analytical table it will be seen that the idea of any striking destruction of organic matter during the river's flow receives no sort of support from my experiments; the evidence is in fact wholly opposed to any such supposition." At first sight it appears strange that such skilled observers should arrive at conclusions so diametrically opposed; but the investigation is beset with difficulties, some practically insurmountable. The water at different points is not the same; even if time be allowed for the water first sampled to reach the subsequent sampling stages, it will be more or less diluted by ground water or by tributary streams, and receive additional polluting matter along its course. The insoluble matter in suspension, or on the bed and sides of the river, may by its decomposition be rendered soluble; hence, unless the rate at which the soluble matters are oxidised and destroyed is greater than that at which the insoluble organic material is rendered soluble, the analysis of the water will show no improvement, or in fact may, as in Professor Frankland's experiments, show even a deterioration. Such deterioration is therefore no proof that a process of oxidation is not taking place; its true interpretation is probably the one just given. This is confirmed by the experiments of Sir F. Abel, Dr. Odling, Dr. Dupré, and Mr. Dibdin, on the oxygenation of the Thames water. "They found that each 1,000 million gallons of water between Blackwall and Purfleet lost from 25 to 35 tons of oxygen, and retained oxygen to the extent of from 5 to 15 tons. The quantity of water passing Erith upwards in the upward flow of the tide was estimated by the engineers to be 40,000 million gallons. This should contain 1,600 tons of oxygen; it was found to contain only 400 tons; thus 1,200 tons must have destroyed thousands of tons of dry organic matter, altogether disregarding the oxygen the river was absorbing from the atmosphere during the whole time the oxidation was going on. The experiments of M. Geradin

confirm these observations; they are published in *Le Rapport sur l'Altération la Corruption et l'assouvissement des Rivières*, and refer to the river Seine. This river before it reaches Paris contains its full amount of oxygen; when it gets to Paris the greater proportion of the oxygen is at once removed, and this removal can only take place by its use in the oxidation of organic matter; a few kilometres farther on the river is found to again contain its normal quantity of oxygen, which fact is accounted for by the organic matter being disposed of."—Professor W. R. Smith, "River Water as a Source of Domestic Water Supply." *Journal of State Medicine*, April, 1894.

The balance of evidence is decidedly on the side of those who uphold the theory of self-purification, and the diverse conclusions arrived at by different observers can be accounted for by the varied and often imperfect character of the experiments, and by the diverse conditions which obtain in different streams. That river water, grossly befouled by sewage in its higher reaches, becomes a few miles lower down so pure, from a chemical point of view, as to be certified by the most eminent analysts to be fitted for all domestic purposes, and is actually so used by millions of our population, is a fact which cannot be gainsaid. Whether this process of purification be merely due to sedimentation and dilution, or to these factors, assisted by oxidation, is, however, a matter of trifling importance, since it is now fully recognised that the disease-producing material is not the dead organic matter in solution, but the living organisms in suspension. The problem is not a chemical one, but a biological one. If the specific disease-producing bacteria can be carried long distances by streams, it matters very little whether they are accompanied by an increased or decreased amount of the soluble impurities which were introduced therewith. Unfortunately biologists differ as widely as chemists in their views, some contending that a biologically impure water may, by a few miles' flow,

supplemented by some process of sand filtration, be rendered biologically pure, whilst others consider that the water of a river specifically infected at any point cannot afterwards be rendered safe for domestic purposes by any such means. The opinion of the biologists who hold the latter view is supported by a large mass of evidence proving that many epidemics of typhoid fever and cholera in this country, in the United States, and elsewhere, were due to the use of river water which had been polluted many miles above the intake of the water supplied to the populations amongst which the outbreaks occurred (*vide* Chapter IX.). As an example of the evidence adduced in support of the former view, may be cited the Report made by the Imperial Board of Health in Mecklenburg on the water supplied to the town of Rostock. This town takes its water from the river Warnow, which, 80 kilometres above, is polluted by the sewage of the city of Güstrow. According to Herr Kümmel,* "The Imperial Board of Health sent a committee to investigate this matter, including an eminent biologist, and these gentlemen made a trip up the Nebel and Warnow from Rostock to Güstrow. . . . They tested the water at various places, from above the town of Güstrow down to the Rostock Waterworks. They found that, though the town of Güstrow deteriorated the water very much, and that the water two kilometres below was polluted much more by a large sugar manufactory, the number of microbes above the town of Güstrow, and that 25 kilometres below the town and below the sugar manufactory, was nearly the same; that whilst in the interval the number of microbes had increased to 48,000 in a cubic centimetre, the number was again reduced to about 200; and at last, just above Rostock, where the river was said to have been deteriorated by the sewage of the town above, the number of microbes was less than it was above the town of Güstrow,

* *Proceedings of International Congress of Hygiene*, vol. vii., p. 183.

and no town at all was situated above the point where the first test of the water was taken. This experiment was made twice—once during the summer, and the second time in October, 1890. The result of the inquiry had been that the Imperial Board had declared the town of Güstrow might send its sewage water into the river."

On the opposite side we may adduce the Report of the Massachusetts State Board of Health on the Outbreaks of Typhoid Fever at Lawrence, Lowell, and Newburyport, referred to in Chapter IX. In the Newburyport epidemic the typhoid bacilli must have travelled from Lawrence, a distance of over twenty miles. The Royal Commission on Metropolitan Water Supply, notwithstanding the amount of evidence given by bacteriological experts, felt bound to fall back upon the "evidence from experience" in order to enable them to decide whether the Thames could safely continue to be used as the source of water supply to the city; but from their report it is quite evident that even on theoretical grounds they regarded the danger of disseminating typhoid fever in London by the use of water from the Thames and Lea as being exceedingly remote. Selecting the year of highest mortality from typhoid fever which has been recorded in recent years, allowing seven attacks for each fatal case, and assuming that the whole of the discharges from all the cases in the two valleys passed directly into the rivers at the period of smallest flow, there would be one typhoid case in the Thames valley to a mass of water 5 miles in length, 100 yards in width, and 6 feet in depth, and in the Lea valley to a similar body of water 3 miles in length. But as only a very small proportion of such discharges ever reach the rivers, the degree of dilution must be much more considerable. This is an attempt at a *reductio ad absurdum* argument, such as Dr. Edwards applied to the Merrimac River (p. 155). The danger arising from the flooding of ditches and pools and the washing down of the contents by heavy rains, is

said to be scarcely appreciable, since the quantity of typhoid matter which would in this manner reach the streams must be excessively small, and a still smaller amount will have retained its power of setting up disease. Typhoid dejecta lose their virulence after a few days, fifteen being probably the maximum, and as the typhoid bacillus does not form spores, it is only from typhoid dejecta of very recent deposit that any danger is to be apprehended, and this clearly reduces very greatly the supposed risk of specific pollution of the water in times of floods. At such times also the volume of river water is vastly augmented, and floods occur chiefly at a time when the temperature of the water is too low to favour the development of the bacilli, and when typhoid fever is least prevalent. The Commissioners also regard typhoid fever as being an exclusively human affection, and that consequently the pollution of water by animal manure, however objectionable it may be on other grounds, cannot be regarded as a possible source of such disease. Pathogenic bacteria in water are in an unnatural medium, and whilst the natural water bacteria increase rapidly, the former undergo rapid attenuation and loss of virulence, and, being worsted in the struggle for existence, they speedily succumb. Direct sunlight also destroys these bacteria, and even diffused light reduces their vitality.

The effect of the sun's rays upon the organisms found in water has been studied by many observers. Dr. Procacci exposed water in deep cylinders to the nearly vertical rays of the sun, and found that all the organisms in the water up to a certain depth were killed. After three hours' exposure the water in the cylinders to 1 foot depth was nearly sterile, whilst at a depth of 2 feet they were unaffected. Professor Buchner exposed gelatine plates sown with typhoid bacilli in water at various depths for a period of four and a half hours, and found that all those plates covered with less than 5 feet of water were sterilised.

Those exposed at a depth of 10 feet were not affected. Percy Frankland has proved that in the Thames and Lea there are often twenty times more organisms present in the water in winter than in summer, but this he thinks may in part be due to the greater proportion of spring water contained in the streams in summer, since spring water contains comparatively few organisms. When a little common salt is added to water the sterilising effect of the sun's rays is said to be increased.

With reference to the great variation in the number of bacteria in river water during the course of the year, Professor P. Frankland, in his Report on Metropolitan Water Supply, 1894, says, "that the number of microbes in Thames water is determined mainly by the rate of the flow of the river, or, in other words, by the rainfall, and but slightly, if at all, by either the presence or absence of sunshine, or a high or low temperature."

Dr. D. Harvey Attfield (*Brit. Med. Journ.*, 17th June, 1893) describes the results of a series of experiments undertaken by him in Munich to ascertain the effect of Infusoria upon the bacteria in polluted water. He concludes that "Infusoria would seem to have some powerful influence in the getting rid of bacteria, and, possibly, so aiding in the 'self-purification' of water."

During the process of sedimentation also a large proportion of the bacteria are deposited. Professor P. Frankland has shown that in the process of softening water by the addition of lime, 98 per cent. of these organisms may be removed in the precipitate. In some recent experiments made by me in connection with a large public water supply, I found that the micro-organisms increased very rapidly in the softened water, so that in a few hours there were more bacteria in it than in the unsoftened water. The investigation was undertaken because the softened water when submitted to bacteriological examination was almost invariably found to contain more organisms than the

original water; moreover, it also contained traces of nitrites. The lime used was sterile. It contained decided traces of nitrites, and was probably made from a limestone containing a trace of nitrates. In the river water as supplied to London no pathogenic bacteria have ever been discovered. It is admitted by most bacteriologists also "that small doses of cholera and typhoid poison may be swallowed with impunity, and some even believe that these small doses act as a vaccine and render the imbiber immune. Theoretically, therefore, the danger of an epidemic of typhoid fever, or even of cholera, from the use of Thames and Lea water would seem to be remote, especially when the additional safeguard of careful sand filtration is introduced. Bacteriology, however, is in its infancy, and our views on many of the above points may have to be considerably modified; and whilst the "evidence of experience" in London has so far justified the conclusion at which the Commissioners have arrived, the same kind of evidence, according to most trustworthy observers in other towns using polluted river water, leads to a very different conclusion. The general acceptation of the Commissioners' views with reference to the use of sewage-contaminated streams would be a great national misfortune, and would, it is to be feared, impede the action of sanitary authorities in their efforts to secure the freedom of our rivers from pollution by sewage. The Commissioners, doubtless, never intended that their conclusions should apply to any other rivers than the Thames and the Lea, and this fact should be carefully borne in mind, since the acceptance as a general principle of a view which is applicable only to a particular case is illogical and may bring about disastrous results.

CHAPTER XIII.

THE PURIFICATION OF WATER ON THE LARGE SCALE.

THE water derived from deep wells, springs, and the subsoil rarely, if ever, requires filtration or any other form of purification. Surface water, if collected in sufficiently large lakes or reservoirs, usually, by sedimentation, becomes so clarified as to require no further treatment. As examples may be mentioned the water supplies to Glasgow and Liverpool, derived from Loch Katrine and Vyrnwy Lake respectively, neither of which is subjected to any form of filtration, the mere subsidence of the suspended matters which enter the lakes with the surface drainage effecting all the purification which is necessary. River water, even if collected in reservoirs sufficiently large to hold several days' supply, is rarely sufficiently purified by sedimentation to be adapted for use without filtration or some other process of purification. The collection of water in large reservoirs not only permits the suspended matters, living and dead, to subside, but the detention of the water in such receptacles affords time for the pathogenic organisms which may be present to lose their vitality, by the action of light, or "by the deleterious action exerted upon them by the harmless water-bacteria" (P. Frankland). On the other hand, the storage of water in large open reservoirs has its disadvantages, as will be pointed out when the storage of water is being considered. All other processes of purification, such as boiling, distillation, and precipitation, are only applicable in special cases or on the small scale; and even after the water has been submitted

to these processes, it usually requires filtering, either to clarify it or render it palatable. Hence filtration is by far the most important method of purification, and an accurate appreciation of the factors necessary to ensure that this is, under all circumstances, as complete as possible, is absolutely necessary if our polluted rivers are to continue to furnish the water supplied to our large centres of population. Until quite recently, the effect of filtration had been considered exclusively from the chemical point of view, and that modification which decreased most materially the proportion of organic carbon or organic nitrogen or albuminoid ammonia was regarded as being the most satisfactory. Inasmuch as this decrease was never very large, the process was not looked upon with much favour or regarded as of very great importance, and hence was often performed in a very careless and haphazard manner. Bacteriological research, however, having demonstrated that certain specific diseases were caused by living organisms, some of which might enter the system with the drinking water, greater attention was paid to the subject, and efforts were made to secure greater clarification and transparency, the results being judged by the examination of samples of the water in long, glass cylinders. By this means some of the more important conditions necessary to ensure the removal of the suspended matters were discovered. Further bacteriological progress, however, succeeded in demonstrating that water which appeared by such a test to be perfectly clarified might still contain very large numbers of those excessively minute organisms, bacteria, certain of which are capable of causing disease; and it is now generally acknowledged that a filter which is capable of effecting almost perfect oxidation of the dead organic matter in a water, rendering it pure from the chemist's point of view, may yet permit of specific bacilli passing through in large numbers. Evidently, therefore, neither chemistry nor the physical test of

transparency can determine whether any process of filtration is efficient. We are, therefore, compelled to resort to the bacteriological test, by which we can obtain some approximate idea of the quantity and character of the organisms which have succeeded in passing through the filter beds. Much remains yet to be discovered in this science before the results of bacteriologists can be implicitly relied upon. The confidence of the Worthing authorities in the bacteriological examination of their water supply proved to be misplaced. We have, however, at present nothing else so trustworthy, and as the study of the process of filtration from the bacteriological point of view has led to most important discoveries, we must accept it as our safest guide.

Professor P. Frankland in 1885 commenced a series of bacteriological experiments bearing on the filtration of water at the London Waterworks, which led him to conclude that to obtain satisfactory results—(1) The storage of the unfiltered water should be considerable, to allow of sedimentation; (2) The filtration should not exceed a certain rate; (3) The depth of fine sand should be considerable; and (4) The filtering materials should be renewed frequently. The effect of subsidence in diminishing the number of bacteria in water, and, therefore, in diminishing the risk of disseminating disease, is well shown in the following table, taken from a paper by Professor Frankland, read at the Edinburgh Congress of Hygiene (1893).

Table showing the Bacterial Effect of Subsidence in the Reservoirs of the West Middlesex New River Companies:—

	No. of Micro-organisms in 1 c.c. of Water.
New River Company at Stoke Newington—	
Cutting above reservoir	677
After passing through first reservoir .	560
After passing through second reservoir .	183

West Middlesex Company at Barnes—	
Thames water as abstracted at Hampton .	1437
After passing through first reservoir . .	318
After passing through second reservoir . .	177

By far the most important and extended series of observations on the purification of water by sand filtration has been conducted by the Massachusetts State Board of Health, and published in their Annual Reports (1890-93). In 1891, investigations at the experiment station having confirmed the belief that the typhoid bacillus was sometimes present in sewage-polluted waters, and was able to live therein for at least three weeks, and further investigations by the Board having proved that high death-rates from typhoid fever result from the drinking of such water, a special study was made "of filtering materials coarse enough to purify a municipal water supply economically, while removing these disease-producing germs." It was proved by these experiments that water could be filtered at the rate of 2,000,000 gallons per acre daily, "with the removal of substantially all the disease-producing germs which may be present in the unfiltered water." The experiments were made with water to which approximately known numbers of the *B. prodigiosus* or *B. typhi abdominalis* had been added. The former bacillus was usually selected on account of the similarity of its life history to that of the typhoid bacillus, and because the results obtained with it were more reliable. The number of bacilli added varied from a small number to several hundred thousands per cubic centimetre. The following table, from the Report for 1892, "shows the average percentages removed of single species of bacteria under favourable conditions, and by filters which can be constructed on a large scale."

No. of Filter.	Rate—Gallons per Acre Daily.	Kind of Bacteria.	Per Cent. Removed.
36 A	1,500,000	*B. typhi abdominalis*	99·93
36 A	3,000,000	*B. prodigiosus*	99·95
33 A	2,000,000	Do.	99·96
34 A	2,000,000	Do.	99·98
37	2,000,000	Do.	99·89

Filter 36 A consisted of 58 inches of sand of an effective size of .20 millimetre, with a loam layer 1 inch deep placed 1 foot below the surface.

Filter 33 A consisted of 60 inches of sand of an effective size of .14 millimetre.

Filter 34 A consisted of 60 inches of sand of an effective size of .09 millimetre.

Filter 37 consisted of 61 inches of sand of an effective size of .20 millimetre.

Such a high degree of efficiency had not before been obtained, and if such results are obtainable on a large scale, the danger to be apprehended from the use of sewage-polluted waters which have been so carefully filtered would seem to have been reduced to a minimum. The filtration at the Altona Waterworks, which Koch believes practically saved the city from an outbreak of cholera, was certainly not nearly so thorough, and the same applies to the filtration of the Thames water as supplied to London, which for so long has secured the inhabitants immunity from typhoid epidemics.

The filtering materials experimented with were placed in galvanised iron tanks about 6 feet deep and 20 inches in diameter, and the rapidity of filtration was regulated by a tap at the bottom. Beneath the effective sand was a layer, 1½ inches thick, of coarse sand, and below this successive layers of gravel, increasing in size, the whole having only a depth of 3½ inches. It was found best to pack the sand dry, as, when introduced with water,

stratification took place. The polluted water was supplied continuously from a small reservoir, the excess passing off through an overflow, so that the depth of water upon the filter bed remained constant throughout the experiments. When the accumulation of suspended matter on the surface of the filter bed impeded the filtration to such an extent that the tap at the bottom when wide open did not pass the water at the prescribed rate, the upper surface of the sand was removed. The sand used was carefully sifted, and its "effective size" determined by further sifting a sample. This size is such that 10 per cent. of the sand is of smaller grains, as ascertained by sifting, whilst the remainder is of larger grains. The results of the Massachusetts experiments may be briefly summarised as follows:—

(*a*) Increased rapidity of filtration with deep layers of sand caused a slightly larger proportion of the bacteria to pass through the filter. With thinner layers still more bacteria were able to pass.

(*b*) With both continuous and intermittent filtration the finer sands are slightly more effective than the coarser ones.

(*c*) The depth of sand within certain limits exerted but little influence except when the water was being filtered rapidly; with moderate rapidity of filtration (2,000,000 gallons per acre daily) 1 foot of sand appeared to be as effective as 5 feet.

(*d*) In filters made of coarse sand, the addition of a loam layer increased the efficiency. When the effective size did not exceed .20 millimetre and the filtration was not too rapid, the loam had little or no influence.

(*e*) The effect of scraping the sand to remove the clogged surface was to cause an increased number of organisms to pass through the filter. The filters required three days' use after scraping usually to reach their maximum degree of efficiency. The effect of scraping was more marked in

shallow than in deep filters, and with high rates than with low rates of filtration.

(*f*) Over 80 per cent. of the bacteria removed were found in the upper inch of sand, and 55 per cent. in the upper quarter-inch. The *B. prodigiosus*, which is very like the typhoid bacillus in its mode of life in water, was not found below the upper inch.

(*g*) The average depth of sand necessary to be scraped from the surface of the filter was a quarter of an inch, but was found to vary with the size of the sand, decreasing as the fineness of the sand increased.

(*h*) Much less water will pass a filter at 32° F. than at 70° F., owing to the increased viscosity of the water.

(*i*) Within certain limits and under equal conditions the quantity of water passed between successive scrapings is not influenced by the rate of filtration.

(*j*) Finer sands require more frequent scraping than coarser sands, whether the filtration be continuous or intermittent.

(*k*) Shallow filters require more frequent scraping than the deeper ones. This appears to be entirely due to the greater head available in the deeper filters for overcoming friction.

(*l*) Filters used continuously require less frequent scraping than when used intermittently.

The bacteriological examination of the effluents from all the filters in July and August showed that a larger number of organisms were then present than at any other time. From the results of the experiments which were instituted to ascertain the cause, the reporters infer:—

1. That during the summer months the temperature or other conditions for continuation of life of bacteria at the surface of filters are more favourable than at any other time.

2. That certain species of bacteria are even able to

multiply there at times during this period, although most species rapidly decline.

3. That this is far less noticeable in the case of intermittent than of continuous filters.

4. That typhoid-fever germs fail to grow under these conditions, so that the hygienic value of filtration is not affected by the growth during warm weather of a very few species of the more hardy water-bacteria.

The above results have been confirmed in important particulars by Dr. Koch, but he has also shown that some of their conclusions must be received with caution. The conclusions at which he has arrived from the study of the outbreak of cholera at Altona, and of other epidemics due to imperfectly-filtered water, are—(1) That the real effective agent in removing micro-organisms from the water being filtered is the layer of slimy organic matter which forms upon the surface of the sand. (2) That if this surface be removed by scraping, or its continuity affected in any way, as by the freezing of the surface, the number of bacteria which pass through the filtering material increases considerably; in fact, both cholera and typhoid germs may pass in sufficient numbers to cause an epidemic amongst those who use the imperfectly-filtered water. (3) That water should not pass through the filters at a rate exceeding 100 mm. per hour (about 2,000,000 gallons per acre daily). (4) That after a filter bed has been scraped, water should be allowed to stand upon it for at least twenty-four hours, to allow of the slime depositing before filtration is commenced, and that the water which first passes through should not be allowed to reach the pure-water reservoir.

At the Altona Waterworks the filtered water has been regularly examined bacteriologically since the summer of 1890. By keeping the pace of filtration below 2,000,000 gallons per acre daily, the bacteria in each c.c. of the filtered water practically always remained below 100;

usually they were much below—20 to 30 being the average. In January, 1892, the number of micro-organisms suddenly increased to from 1,000 to 2,000 per c.c., and in February an outbreak of typhoid fever occurred. Suspicion was expressed that filtration might have been disturbed by ice formation, or by the superficial layers of sand becoming frozen during the process of cleansing in the keen frosty weather; but absolute proof was not forthcoming. In January and February, 1893, the epidemic of cholera occurred in the town, and this had been preceded by an increase in the number of bacteria in the filtered water. On the 30th December, 1892, the number of germs began to increase, and reached on the 12th January, 1893, the number of 1,516, and remained high until early in February. Up to this time the water from each filter bed, of which there were ten, had not been examined separately; when so examined, from the 1st of February Filter No. 8 was found to be acting worst. On the 3rd this filter was examined, and when the water was drawn off it was found that the sand layer was frozen at the top. The freezing had taken place during the period of cleansing.

Koch also points out that winter with its period of frost is not the only enemy of filtration. Occasionally in summer, river and stored surface-water is so rich in vegetable growths that these rapidly form an almost impervious layer upon the surface of the sand, and to keep up the supply of filtered water, greater pressure and more frequent cleansing are necessary, both tending to give a filtered water which is imperfectly purified. These disturbances, however, are only dangerous to the public health when the natural water contains specific bacteria, and as the whole filters are never affected at the same time only a portion of the disease germs could ever pass. Yet that even this part can cause epidemic outbreaks is proved by the experience of Altona, Berlin, and other places. To secure efficient filtration Koch lays down the following rules:—

1. The pace of filtration must not exceed 100 mm. in the hour. To make sure of this each separate filter must be provided with a contrivance by which the movement of the water in the filter can be restricted to a certain pace, and continually regulated so as to keep that pace.

2. Each separate filtering basin must, when in use, be bacteriologically investigated once each day. There should, therefore, be a contrivance enabling samples of water to be taken immediately after they have passed the filter.

3. Filtered water containing more than 100 germs, capable of development, in a cubic centimetre should not be allowed to reach the pure-water reservoir. The filter should, therefore, be so constructed that insufficiently pure water can be removed without its mixing with the good filtered water.

4. The filter beds should be of small area, far smaller than those used in London,* or recently constructed at Hamburg.

At the same time Koch admits that in waterworks of good construction and intelligent management, Rule 2 need only be strictly observed in times of danger. He is also bound to admit that the standard of 100 germs per c.c. is arbitrary, and is only "intended to give a basis obtained from experience to form a proper judgment." There are strong grounds for suspecting that at Altona a number of cases of cholera occurred, though not an epidemic outbreak, during the period when the filtration was up to Koch's standard, and that these were due to the water being specifically infected. As the typhoid bacillus is much smaller than the cholera germ, it would seem probable that the danger of disseminating typhoid fever by the distribution of imperfectly-filtered water is greater than in the case of cholera.

Prior to the investigations of the Massachusetts State

* The average size of these is one acre.

Board of Health, the small amount of chemical purification produced by sand filtration was attributed to the oxidation of the organic matter by the oxygen held in the pores of the sand. By the experiments above referred to the oxidation was proved to be due to the action of nitrifying organisms, which adhere to the sand. When nitrification has been well established in a filter, the rate of filtration within certain limits was found to exert but little influence upon the removal of the organic matter. Also, within certain limits, the effect varied little with the degree of coarseness of the sand, but deeper filters were more efficient in removing the organic matter than shallower ones. In some experiments with filters in which the nitrifying action had become well marked, the albuminoid ammonia yielded by the effluent was 80 per cent. less than that yielded by the water before filtration. The importance of removing as much as possible of the organic matter is due to the fact that the food supply available for the bacteria which are present is reduced thereby, and their growth and multiplication in the water subsequently is retarded.

Experiments which were made with the coloured water of the Merrimac River proved that new sand removed the colour more efficiently than sand which had been in use some time. One filter of sand and loam continued to remove all the colour for over two years; after the end of the third year the water which passed through was very slightly but uniformly coloured.

The oxidising effects produced by sand filtration are, however, in the light of recent bacteriological research, of very secondary importance in the purification of water. Any considerable chemical purification cannot be constantly relied upon when water is treated on a large scale. New sand filters have but little action. It is only when they have, so to speak, become charged with the nitrifying organisms that any appreciable effect is produced, and it takes some time for this action to become well established.

Moreover, the nitrification, after proceeding satisfactorily for a time, may suddenly cease, to commence again after a more or less lengthy interval. The cause of this intermittent action is difficult to explain. The Massachusetts investigators think that the action probably only commences when a certain quantity of nitrogenous matter has become stored up in the pores of the sand. It then proceeds rapidly until this is consumed, and again ceases until a further quantity has accumulated, and this may require months. Another singular fact is that the total nitrogen in the unfiltered water almost invariably exceeds that found in the filtrate, which appears to indicate that some of the nitrogen is liberated in the gaseous state and escapes into the air.

The filter beds of the eight London Water Companies exceed 100 acres in area. The depth of sand used by the various Companies varies from 2 feet to 4 feet 6 inches, and the depth of the filter beds from 2 feet 9 inches to 8 feet. The following description of the Leeds Waterworks may be cited as an example of the most modern system of sand filtration. The water from the Washburn valley and moorlands is collected in a reservoir 195 acres in extent, and capable of holding a year's supply. From this it passes to a settling pond, having an area of 3 acres, and capable of holding 10,000,000 gallons. A certain amount of water, however, is collected, which flows directly into this settling reservoir. From here it flows on to the filter beds, seven in number, each having an area of nearly an acre. The filter beds consist of 2 feet of fine sand, 3 inches of pea-gravel, 3 inches of $\frac{1}{2}$-inch gravel, 4 inches of 1-inch gravel, and 9 inches of rough stones. The water, after passing through the beds, enters a series of perforated pipes 3 and 4 inches in diameter, all of which discharge into a main culvert along the centre, terminating in a small circular, covered tank, where observations can be made as to the rate at which the water is passing through

the bed. The filtered water is then conducted into a service reservoir. In the middle of each bed is a rectangular iron box, used for washing the sand scraped from the surface of the filter during the process of cleansing. The filters are cleaned in order, one each week on an average, from $\frac{1}{4}$ to $\frac{3}{8}$ of an inch of the surface being removed. This is wheeled along planks to the washing box, and after being washed is again replaced. When the tanks are emptied for cleansing, the water is only drawn off to near the bottom of the sand, and in refilling the water is backed up from below, and not discharged on to the surface, as this would disturb it and impair the efficiency of the filtration. The air in the sand escapes not only from the surface, but also from escape pipes, which pass through the walls of the tanks. If this precaution be not taken the air may cause fissures to form in the sand. When the water has risen above the surface of the sand it is then turned on from above, and flows over the side of a trough, so as to be uniformly supplied to the filter with the minimum amount of disturbance. Eight men are constantly employed in keeping the filters in thorough working order. On an average each square yard of filter passes 412 gallons of water per twenty-four hours. The head of water, or rather the difference in level between the surface of the water on the filter and in the circular tank into which the filtered water is discharged 4 to $4\frac{1}{2}$ feet.

Table VIII. gives the area in acres, rapidity of filtration, etc., of the filter beds of several large public supplies, compiled from a report of a sub-committee of the Dumfries Town Council, which considered the subject with the view of improving their filtering arrangements. The River Commissioners on Metropolitan Water Supply reported that, as a general rule, the filtration of water by the London Companies was carried out efficiently, from 98 to 99 per cent. of the organisms being removed from the water. The occasional failures, they thought, could be

TABLE VIII.

Area of Filter Beds, Rate of Filtration, etc.

Names of Companies.	Capacity of Subsidence Reservoirs.		Filters.		Thickness of Sand in Filters.		Monthly Rate of Filtration per Square Foot per Hour, 1891.	
	Cubic Contents.	Number of Days' Supply.	Area.	Area per Million Gallons of Average Daily Supply.	Maximum.	Minimum.	Mean Monthly Averages.	Maximum Monthly Averages.
	Gallons.		Acres.	Acres.	Ft. ins.	Ft. ins.	Gallons.	Gallons.
New River . . .	169,000,000	5·1	16½	0·50	2 3	1 5	2·08	2·30
East London . . .	615,000,000	13·7	29¾	0·67	2 0	1 4	1·33	1·33
Chelsea	140,000,000	14·2	6¾	0·68	4 6	3 6	1·75	1·75
West Middlesex . .	117,500,000	7 0	14	0·88	3 3	2 6	1·25	1·33
Grand Junction . .	64,500,000	3·5	17¾	0·96	2 0	1 3	1·99	2·25
Lambeth	128,000,000	6·5	9½	0·48	3 0	2 6	2·15	2·36
Southwark and Vauxhall	46,000,000	1·8	14½	0·55	3 0	1 6	1·5	3·50
					Feet.		Gallons.	
Leeds	10,000,000	...	6	1·20	2		1·9	
Wakefield	...	10·0	1¼	1·25	1½		1·71	
Bradford	..	...	4½	·90	3½		2·09	
Leicester	...	...	2½	·87	2		1·68	
Carlisle	...	..	$\frac{6}{10}$	·90	2½		1·07	
Dumfries	..	..	¼	·26	...		4·33	

remedied by increasing the number of filter beds or by having recourse to double filtration; "and assuming the water to be invariably as efficiently treated as it is usually by the most careful of the Companies, the raw waters of the Thames and Lea can be transformed, in the judgment of Prof. P. Frankland,—who, as is well known, has been no sparing critic of the London water,—into a beverage quite as good, from the point of view of health, as deep-well water." This opinion, it must be remembered, is not shared by many other sanitarians of equal eminence. In any case it is obvious that only the efficiency of the filtration can safeguard the metropolis from outbreaks of typhoid fever and possibly of cholera. Doubtless, however, the Water Companies will not be slow to adopt the recommendation of the Commissioners, and will take every precaution suggested by the breakdown of the filtering arrangements at Altona.

The area of filtering surface required is given by the formula $A = \frac{Q}{F}$, where Q is the maximum daily demand in cubic feet, F the filtering rate in feet, and A the required area in square feet. This area must always be available; hence an additional area must be provided for use whilst other portions are being cleansed. According to Hennel the number of filter beds required for different populations is as under:—

Population.	No. of Filter Beds.
2,000	2
10,000	3
60,000	4
200,000	6
400,000	8
600,000	12
1,000,000	16

These include filter beds out of use for cleansing.

In all cases a sufficient number of filter beds should be

provided, to allow of the cleansing and renovating of one set without overworking the remainder. The filtration must not be too rapid, not over 2,000,000 gallons per acre daily. To accomplish this the head of water must be reduced after cleansing, and gradually increased as the pores of the sand become closed by the slimy matter which settles on its surface. By "filtering head" is meant the difference between the level of the water on the bed and in the well which receives the filtered water. After cleansing a few inches of head may be sufficient; when it exceeds 3 feet the surface again requires renewal. Each bed should have an arrangement for regulating the flow, and the water should be admitted into the filter beds in such a manner as not to disturb the surface. The surface sand when removed for cleansing may be washed in hoppers admitting the water from below, or in troughs through which water is constantly flowing. Deep filter beds keep the water cooler in summer and retard freezing in winter, the latter being the more important, since freezing not only interferes with the efficiency of the filtration, but may damage the walls of the filter beds, by the expansion of the surface water in the act of freezing.

In many places water is obtained from galleries or trenches sunk along the edge of lakes or running streams, the general impression being that the water so obtained is derived from the lake or stream, and that it undergoes a process of natural purification and filtration in its passage through the intervening soil. In many cases, however, this is really ground water which is intercepted on its way to its natural outlet. Such water is usually very free from organic matter, and contains but few bacteria. Where the ground water falls below the level of the water in the stream or lake, doubtless a certain quantity of the water which passes into the galleries is derived from the latter sources, and is not so likely to be of good quality, since it only passes through soil which is constantly saturated

with water, and therefore never aerated, and destitute of any oxidising powers. In such cases also the filtration is liable to be inefficient, and to allow of bacteria and other particulate matters passing into the collecting channels.

Many attempts have been made to filter water on the large scale without employing filter beds, which are expensive not only on account of the space required, but of the constant labour and attention required to keep them in a state of efficiency. One of the best-known processes is that of the Atkins Filter and Engineering Company, which is in use by the Henley-on-Thames Water Company, and has been adopted by many large institutions. The filtering apparatus, technically known as the "Scrubber," consists of a perforated metal cylinder to contain the sand or other filtering material, fitted into a tank and so arranged as to revolve easily by turning a handle. The cylinder is only partly filled with the filtering material, and the collecting tubes, which convey away the filtered water, lie as nearly as possible in the centre of this as it lies in the cylinder. To clean the filter it is only necessary to turn the handle, when the cylinder revolves, agitating the filtering material with the water, and the latter, together with the impurities washed out, are run off through a by-pass. Several such "scrubbers" can be connected together. By another arrangement the sand is put into a number of discs fitted on a revolving centre collecting-tube. The water filters through the flat surface of each disc, so that the area of filtering surface is much increased. More perfect filtration can be secured by passing the water through two "scrubbers" in succession, and affords, naturally, safer results for drinking water. The Company claims that, with an area of only 600 square feet, their machines will filter as much water as an acre of filter bed (3,000,000 gallons per day). Under the latter system the cost of cleansing is said to be from 5s. to 10s. per million gallons, whereas it is only about half the amount

with the Atkin "scrubbers," with "the great sanitary improvement of *daily cleansing* in addition." Such machines for rapid filtration do not appear to be regarded with much favour in this country, and there are no records of the bacteriological examination of waters which have passed through these filters. The conditions laid down by the Massachusetts Board as being necessary for perfect filtration not being observed, experimental evidence of efficiency is much to be desired. Other machines of a similar character—the "Loomis," the "Duplex," the "Hyatt," the "Bowden," etc.—are, however, in use in the United States, chiefly for filtering turbid river-water. A commission appointed by the city of Pittsburg has recently (1899) presented a report containing the results of a number of experiments comparing the efficiency of sand and mechanical filters when used for the river water supplying the city. They found that the use of a coagulant was necessary in both systems, but preference was given to sand filtration. The report states: "With an amount of sulphate of alumina which makes the cost of the two processes substantially equal the mechanical filters yield effluents containing from two to three times as many bacteria as the sand filters." Dr. P. S. Wales, Medical Director, United States Navy, states that, with these mechanical filters, 98 per cent. of the micro-organisms can be removed, but that spores readily pass through the filtering material. (The typhoid and cholera bacilli are not known to form spores.) The four machines above referred to have been used for experimental purposes at the Museum of Hygiene, Washington, D.C., and gave very satisfactory results. The system of rapid filtration is pursued, amongst other places, at—

Oakland, Cal., capacity for 24 hours			.	4,000,000 gallons
Atlanta, Ga.	,,	,,	.	3,000,000 ,,
Long Branch, N.Y.	,,	,,	.	2,000,000 ,,
Ottumwa, Iowa	,,	,,	.	1,500,000 ,,
Athol, Mass.	,,	,,	.	1,000,000 ,,

The city of Alleghany, Pa., was contemplating erecting a plant for filtering 30,000,000 gallons per day, when Dr. Wales's paper was published.* These filters appear to be especially applicable for the waters of muddy, rapid rivers, which speedily clog the ordinary sand filter, and arrest the flow of water. To expedite the process of sedimentation so as to remove more of the suspended matter before passing the water into the filters, alum is largely used. The addition of about half a grain per gallon, on the average, is sufficient. At the Atlanta Waterworks, during 1890, 253 lb. of alum were used per day, corresponding to 617 grains per 1,000 gallons. Some waters, such as that of the Potomac, cannot be clarified without a coagulant. Ferrous sulphate has been used in some cases instead of alum, and with advantage. In this country the water supply to the village of Ingatestone (Essex), previously referred to, derived from a fine, sandy clay, for years resisted all our efforts to clarify it. Alum, or rather Spence's Aluminoferric, was used as a coagulant, and the water then filtered through vertical sheets of flannel. This not proving satisfactory, various recently-introduced filtering and purifying materials were experimented with. Finally, at my recommendation, a filter bed was made of sand and polarite mixed in equal proportions, and with a few inches of fine sand on the top. This filter for several years answered admirably, and the use of the alum was discontinued. Two beds were prepared, so that one could be used whilst the other was cleansed and allowed to rest for re-aeration. A fresh source of supply is now being sought.

At the Antwerp Waterworks, "spongy iron," together with gravel, was used as filtering material, but the beds choked up gradually and the iron became almost inactive.

* *Transactions of International Congress of Hygiene*, London, 1891, vol. vii.

For three years, however, the results were satisfactory, so far as regards the purification of the water. To meet the difficulties just referred to, Dr. W. Anderson, F.R.S., invented the "Revolving Purifier," which has been in use at Antwerp since 1885, and has also been adopted at Boulogne-sur-Seine, Agra, Monte Video, and other places. The apparatus is described by the inventor as a "cylinder supported horizontally on two hollow trunnions, of which one serves for the entrance and the other for the exit of the water. The cylinder contains a certain quantity of metallic iron, in the form either of cast-iron borings, or, preferably, of scrap iron, such as punchings from boiler plates. The cylinder is kept in continuous but slow rotation by any suitable means, the iron being continually lifted up and showered down through the passing water by a series of shelves or scoops fixed inside the shell of the cylinder. By this means the water, as it flows through, is brought thoroughly into contact with the charge of iron, which, in addition, by its constant motion and rubbing against itself and the sides of the cylinder, is kept always clean and active. During its passage through the apparatus the water takes up from $\frac{1}{10}$ to $\frac{1}{5}$ of a grain of iron per gallon, which is got rid of either by blowing in air or by allowing it to flow along shallow open troughs. The oxide thus formed may settle in subsidence reservoirs, or may be filtered out by rapid passage through a thin layer of sand. At Boulogne the average amount of organic matter removed by this process from the Seine water was 63 per cent., and the microbes, which in the unfiltered water ranged from 800 to over 7,000 per cubic centimetre, were reduced to an average of about 40. The bacteriological results are admittedly only approximate, and on one occasion, at least, a large number of bacteria were found in the filtrate. It seems probable that, compared with sand filtration as usually conducted, the revolving purifiers may destroy a larger proportion of the dissolved

organic matter; but unless supplemented by careful sand filtration it would be unsafe to assume that a specifically-polluted water could be rendered safe for drinking purposes by passing through one of these cylinders.

Whilst sand is almost universally employed for the filtration of water on the large scale, and usually is the sole effective filtering medium, in a few instances other materials have been used, together with the sand, either mixed therewith, or in layers. A carbide of iron (Spence's Magnetic Carbide) was in use for a large number of years for filtering the excessively-polluted Calder water for the domestic supply to Wakefield. This water was not only fouled by sewage, but also deeply discoloured by the refuse from dye-works; yet the filters converted it into a colourless, palatable water. The layer of carbide was in use for nearly thirty years, and was never renewed; all that was found to be required was the cleansing of the surface sand. The filtration was intermittent, to allow of the aeration of the filter. The magnetic carbide is also in use at Calcutta for filtering the turbid and polluted waters of the Hooghly, and at Cape Town, Demerara, and other places. Its use was discontinued at Wakefield because a purer supply has been obtained from another source. Spongy iron, polarite, and other insoluble iron compounds are used for similar purposes, and are useful in special cases, as in the examples given. Now that the removal of dissolved organic matter is considered to be of much less practical importance than the removal of the living organisms, less importance is being attached to the use of such materials, and it can only be under exceptional conditions that these aids to sand filtration are necessary. It is upon the proper use of sand that the real efficiency of filtration must depend, though where desirable this may be supplemented by the use of other filters, or the introduction of a layer or layers of other materials; and the substances above enumerated, yielding nothing to the water, yet exerting an oxidising action upon

the organic matter, are probably the best which have yet been discovered.

At Reading Waterworks polarite is now largely used for filtering the water of the Kennet, a polluted, navigable stream. The following description of the filters is taken from an excellent paper read by Mr. Walker the Waterworks Engineer, at a recent meeting of the County Association of Municipal Engineers held in Reading:—

"The process of purifying the river Kennet water is by natural percolation, through a series of filters or chambers, the first chamber containing coke, and the second and third chambers 'polarite,' granulated in two sizes; there are also intermediate or regulating water chambers for facilitating cleaning out, the water passing from the last polarite chamber into a distributing channel, and on to sand filters, as it has been said, to make doubly sure of filtered water; but subsequent experience has proved that perfect purification can be obtained by polarite chambers without the aid of sand. The first two sets of these chambers were started in work in November, 1892. Each polarite chamber measures 40 feet by 9 feet, and has a depth of 2½ feet of polarite, giving an area of 40 yards super each chamber, or a total of 160 yards super for the two sets. By adding the 2½ feet of polarite in each set it gives a depth or thickness of 5 feet to each set of chambers, and an area of 80 yards super per set. From December, 1892, to August, 1893, there had passed through these two sets a total quantity of 409,880,000 gallons of water, giving an average of 18,848 gallons per yard super per day. Two additional sets were started in August last, 1893, of the same dimensions as the above, giving a total area of 160 yards super, with a depth of 5 feet for each set of chambers, which have passed on an average 12,500 gallons per yard super per day. From 1st January of the present year (1894) to the 31st of March last, 190,218,319 gallons of water have passed through these chambers giving an average of

13,215 gallons per yard super per day, or at the rate of 550.6 gallons per yard super per hour. The water has been such that no complaints (which previously were an every-day occurrence) have been made since purification by polarite came into full working order. It has had a most severe test during the past and previous autumn and winter seasons, but like many a good engineer it has often been overworked, but has stood it well. From experience gained in connection with the treatment of the river Kennet water, there is no hesitation in stating the opinion that 'polarite,' as applied here, is capable of effectually purifying a river water-supply for all purposes, and the system can be carried out at less cost of construction and maintenance than filtration by large areas of sand beds."

The effluent from the polarite filters is afterwards passed through four sand filters, each having an area of 10,000 square feet. As these filters pass about 2,000,000 gallons per day, this is at the rate of over 8 gallons per square foot per hour, or four times the average of the London Water Companies.

An addition has since been made by the construction of a covered filter-house, having four sets of chambers capable of purifying 1,000,000 gallons per day. This occupies an area of 424 yards, including brickwork. These chambers were set to work in June 1898, and have given very satisfactory results. It is now 9 years since polarite was introduced in the Reading works, and Mr. Walker's further experience has confirmed his previous report.

In connection with these works also there is an improved system of sand-washing, which was invented by Mr. Walker. Cone-shaped hoppers, mounted on trunnions, and connected at the bottom of the inverted cone with the water supply under pressure, are filled with the sand scrapings to be washed. The water is then turned on, and the upward rush keeps it in a continuous state of agitation, and the impurities are carried off by an outlet at the rim of the

hopper. By this process sand-washing is not only less laborious, but less expensive than by the older methods. One man can wheel, tip, and wash 9 to 10 cubic yards of sand per day at a cost of 3¾d. to 5d. per cubic yard. By the older processes the cost was from 1s. 6d. to 3s. per cubic yard.

The addition of chalk or limestone to soft waters to prevent the action upon lead can scarcely be described as a process of purification, but inasmuch as it is a process which would usually be associated with that of filtration it may be mentioned here. By the admixture of limestone or chalk with the sand the acidity of the water is neutralised, and usually a small amount of carbonate of lime passes into solution. Dr. Scatterty (*Public Health*, May, 1895) describes the filtering arrangements made to neutralise the plumbo-solvent action of the peaty water supplied to Keighley. He says: "These works, completed at a cost of £18,000, consist of three beds of Welsh coke (to extract the grosser peaty impurities), four sandstone and limestone filters, four polarite chambers, and a clean water reservoir. By this filtration the acid so invariably found in moorland water supplies is neutralised by the limestone of the filters, and by this means it is hoped to completely destroy the solvent action of the water on the lead piping." At Clitheroe (Lancashire) a peaty water is filtered and rendered incapable of acting upon lead by being passed through beds of sand, Welsh anthracite coke, and polarite, the works costing £19,000. This process removes the peaty colour, renders the water neutral, and increases the hardness to 2°, which is found sufficient to prevent action upon lead pipes.

Water, when softened by the addition of lime, usually undergoes an improvement in quality, the precipitate of carbonate of lime carrying down with it a certain proportion of the microbes previously suspended in the water. The filtration through sand which follows, to

remove the last trace of carbonate, still further purifies the water, so that the softening process has a double advantage. As this process is primarily conducted for removing the carbonate of lime, and not for the removal of organic matter, and is of very considerable importance, it will be fully considered in a later chapter.

At Oudshoorn (Holland) the water supply is being treated with ozonised air and is said to be sterilised thereby.

Machines have been devised for sterilising water on a large scale by means of heat. I recently tested one of these, but found that it failed to destroy the typhoid bacilli which had been introduced.

Several forms of high-pressure filters have been introduced into this country of recent years, and have been adopted for filtering turbid water for manufacturing purposes. They are doubtless very useful for clarifying water, but my experience leads me to the conclusion that they may be worse than useless if used for filtering water for domestic purposes. In two instances, recently, I have had to recommend small water companies, who had purchased these filters, to abandon their use, since I found the clarified water contained many more micro-organisms per c.c. than the unfiltered water.

CHAPTER XIV.

DOMESTIC PURIFICATION.

THE water supplied by a public company can scarcely be considered wholesome if it requires filtration by the consumer, yet in many towns unfiltered surface water is distributed, and as this often contains visible suspended impurities, some form of filtration must be resorted to if the water is to have a bright and pleasing appearance. The forms of filter generally employed for purifying all the water consumed in a dwelling may be classed under two heads—(*a*) low-pressure filters, (*b*) high-pressure filters. The latter are directly in communication with the service pipe, and the water is filtered through under the pressure in the main; whilst the former are indirectly connected by means of a ball-cock, the only pressure being the column of water in the filter above the filtering material.

The high-pressure filters may contain any of the materials ordinarily used for clarifying water, either in a granular condition and tightly packed or in one porous mass. (Animal charcoal, polarite, magnetic carbide, carferal, silicated carbon, etc.) No doubt for a time such filters remove a considerable portion of the suspended matter, but they can never be trusted to remove more than a small portion of the bacteria, the most dangerous of the constituents. The separated filth accumulates, and to remove it there is usually an arrangement permitting of water being forced through in the opposite direction, whereby much of the dirt is washed away. All of it cannot

be thus removed; hence the efficiency of the filter is more or less rapidly impaired, and the filtering material requires constant renewal. Unfortunately, purchasers of such filters are rarely aware of this fact, or, if they are, the trouble and expense causes such renewals to take place at very long intervals. The whole system is wrong, and

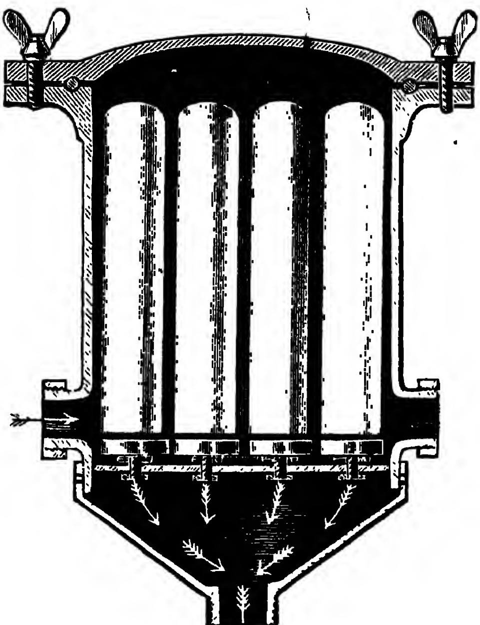

FIG. 14.

should not be encouraged. Even if carefully attended to such filters cannot be depended upon for any length of time, and as they possess few advantages over low-pressure filters their use should be abandoned. The best filters of this class are Major Crease's, the Berkefeld and Pasteur filters. The former consists of a stout cylindrical vessel filled with carferal, a compound of iron, alumina, and

carbon. The water passes in from the main at one end, and out to supply the house from the opposite extremity The filtering material within the cylinder is packed between two perforated plates, one of which can be screwed down upon the other so as to obtain any required degree of compression. It can also be readily unpacked for cleansing or for renewal of the carferal. The "Berkefeld" is, strictly speaking, a bacteriological filter, its object being, not the oxidation of dissolved organic matter, but the removal of the whole of the suspended matter, including the most minute organisms. The filtering cylinder is composed of compressed fossil earth (*Kieselguhr*), and the water is purified by filtration through the side. The suspended matters removed from the water remain upon the surface, and can easily be washed or brushed away, and the cylinders can be resterilised by being placed in warm water and boiled for an hour. Fig. 14 is a section of a cistern filter working with a pressure of 20 lb. upwards. A 3-tube filter of this kind will supply 50 gallons of water per hour.

A smaller, single-tube filter is shown in Fig. 15. It is intended for attachment to the water supply either from a constant main service, with a pressure of, say, 30 lb. upwards, or from a cistern not less than 20 feet above where the filter is fixed.

The Pasteur or Chamberland-Pasteur filter is very similar to the Berkefeld, but is made of china clay, is somewhat harder, and therefore not so readily fractured. Both are efficacious at first, but the latter is said to yield a more palatable filtrate. To the use of the Pasteur filter by the French army during recent years is attributed the great decrease in the mortality from typhoid fever amongst the soldiers (50 per cent.). In other instances, when used for manufacturing purposes, their use has been discontinued on account of the slowness of the filtration, and because after prolonged use the filtered water was no longer

bacteriologically satisfactory. In a series of experiments made by Dr. Johnston, bacteria were found in the water passing through a Berkefeld filter within from 3 to 10 days of continuous use. The Pasteur filtrate remained sterile for six weeks. Recent experiments made by Dr. Sims Woodhead (*Brit. Med. Journal*) confirm the superiority of the Pasteur filter.

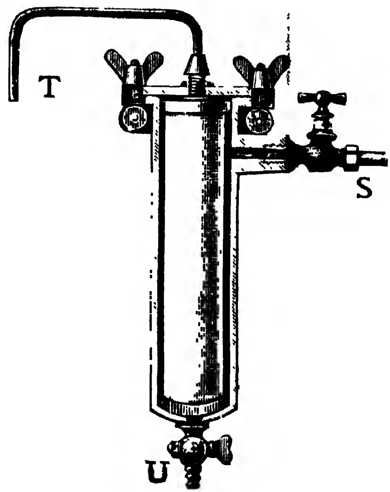

FIG. 15.

S. Water-inlet.
T. Outlet for filtered water.
U. Outlet for water used for washing cylinder.

A number of forms of these high-pressure filters are made for fixing to taps, pumps, etc. They yield a water which at first is absolutely free from micro-organisms, and as they are extremely simple in construction and admit of being very easily cleansed, no other filter can be compared with them for high-pressure work.

Bailey Denton's self-supplying filter may be taken as typical of the low-pressure service filter.

The upper compartment contains the filtering material, which may be sand, charcoal, or any other of the substances used for such a purpose, and is fed from the house cistern at a higher level. When the filtered water in the tank below reaches a certain level the supply to the filter is cut off, and the remaining water as it drains from the filtering material is replaced by air, so that the filter is frequently aerated. If fixed in an easily accessible situation, the material can be examined and removed for cleansing as often as may be required. The capacity of the lower compartment is made suitable for the actual requirements of the household.

Rain water may be effectually filtered by some such arrangement as the above, and if for any reason the reservoir for the filtered water is below the level of the ground, the water may be raised by a pump. Even with this system of treatment the rain water should be collected by means of a "separator," in order to prevent an unnecessary amount of filth being passed into the storage cistern, which not only fouls the water but causes the filter to require much more frequent cleansing.

The number of domestic filters in the market is enormous, and it may truthfully be asserted that the majority of them are worthless. Some are intended merely to remove a portion of the dissolved organic matter, and fail entirely to remove any bacteria which may be present. Others, which claim to remove the micro-organisms, only do this imperfectly and for a short time, and after being in use for a period the filtered water may actually contain more bacteria than were present in the unfiltered water. The use of such filters engenders a false feeling of security, and the users may fall victims to their misplaced confidence. I have had occasion to examine several much-vaunted filters, and found them absolutely useless; they were coarse strainers and nothing more. The so-called "table filters" are usually the least reliable, since the amount of

filtering material is too small to purify the water for any length of time, if at all; and if the material be made sufficiently compact to prevent the passage of micro-organisms, the rate of filtration is excessively slow, and the pores of the filter become rapidly choked. The Berkefeld and Pasteur filters are probably the most reliable, but are very slow in action. The tubes must be frequently removed, washed, first with water, then with a

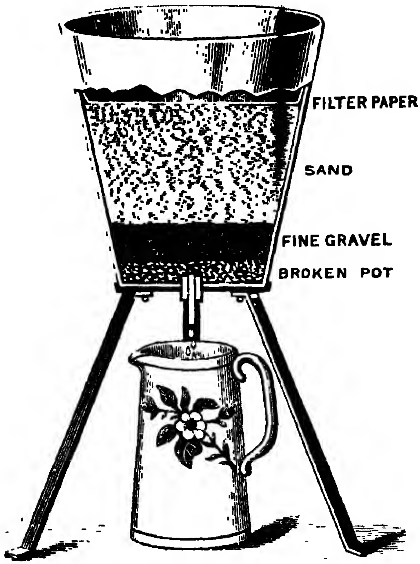

FIG. 16.

dilute solution of permanganate of potash, and finally sterilised by boiling or by heating over a charcoal stove or Bunsen burner.

For ordinary domestic purposes an inexpensive sand filter, which can be made by any person is as good, or better, than many of the high-priced filters in the market. The following is a description of a cottage filter costing only a few pence:—Take a large-sized earthenware flower-

pot, and plug the hole at the bottom with a cork, through which passes a short piece of glass tube. Upon the bottom place a few fragments of a broken flower-pot (pieces $\frac{1}{4}$ to $\frac{1}{2}$ inch square). Upon these place a layer of small, clean-washed gravel, and upon this 6 to 12 inches of well-washed, *fine, sharp* sand. Cover the smooth surface of the sand with a circular piece of coarse filter paper and sprinkle over this a few pieces of the small gravel. Mount the pot on a tripod or other convenient stand, and it is ready for use. The paper prevents the upper surface of the sand being disturbed by pouring in the water, and can be removed, together with most of the sediment which has formed thereon, as often as necessary. Every few months, or oftener if required, the sand can be thoroughly washed and replaced. A layer of finely-granulated polarite and sand, in equal quantities, may be substituted for the lower half of the sand layer, and improves the character of the filtered water in some instances, especially where the water to be filtered contains much vegetable organic matter, as is usually the case when taken from ponds. For the polarite, magnetic carbide, spongy iron, or animal charcoal may be substituted to suit particular circumstances Animal charcoal, from the remarkable power which it possesses of removing certain colouring matters from water, and of absorbing or oxidising organic matters generally, of a complex character, used to be considered one of the best, if not the best, of all filtering materials. Water, however, which has been in contact with it forms a favourable medium for the growth of low forms of life, and bacteria grow within its pores. Professor P. Frankland found that for some days animal charcoal removed most of the bacteria, but that it gradually lost this power, and before the end of a month the filtered water contained many more germs than the unfiltered. It will remove traces of lead, but this property it does not retain for any lengthened period. Vegetable charcoal, ground coke, and

other forms of charcoal also are used as filtering media, but they do not possess the decolourising and oxidising powers of animal charcoal. They are equally efficacious in removing low forms of life, and retain this property longer. Ground slag, pumice, sandstone in slabs, etc., are occasionally employed in filters, but possess no advantage over good sand. Sponge soon become foul, and only acts as a coarse strainer; its use is not recommended.

Whatever material be used, it must be remembered that it can only retain its efficiency for a limited period, and no filter should be purchased which does not permit of the filtering media being easily removed for cleansing or renewal. The filter should also contain a sufficient amount of the material to produce something more than a mere straining action. If not of sufficient depth, it may remove all the coarser suspended matters, and the water appear bright, yet the micro-organisms may pass through with the utmost ease. Earthenware vessels are the best for containing the filtering medium. Galvanised iron is easily acted upon, and may contaminate the water with zinc. Wooden casks may be used if the inside has been previously well charred, and if the charring be repeated occasionally.

When drinking water is of suspicious quality, and there is the slightest doubt about the efficiency of the filtration, it should be well boiled before use, say for ten minutes. This kills everything save certain very resistant spores; but as there are good grounds for believing that none of these spores are disease producing, their presence is of little consequence. It is better to use the water soon after cooling and before the spores have had time to develop. Boiling also removes most of the carbonates of lime and magnesia, rendering the water softer; as the dissolved gases are also given off, its taste is flat and insipid. It can easily be again aerated by pouring through a cullender or sieve from some little height, when the finely-divided streams of water again take up gases from the air.

By distillation a pure water may be obtained from the sea, and from other salt-laden or impure waters. The saline matters remain behind in the boilers, and the steam, when condensed, can only contain any traces of volatile impurities which may have been present. These volatile substances have been charged with causing diarrhœa, but it is much more probable that the illness was due to defective distillation allowing some of the impure water to gain access to the vessel in which the distilled water was being condensed or collected. By aeration the insipid flavour of distilled water may be improved.

When tea or coffee is made with boiling water, the astringent matter in the leaves or berries may tend to produce still further purification. In many epidemics of typhoid fever, it has been noticed that persons who drank the infected water only when made into tea or coffee escaped entirely.

Turbid and polluted waters are sometimes clarified by the addition of from 2 to 6 grains of alum to each gallon, a very little lime also being added if precipitation is not sufficiently rapid. The flocculent precipitate which forms carries down with it most of the bacteria. Perchloride of iron is sometimes used instead of alum, and for the same purpose.

Where only foul-smelling, impure water is obtainable, Dr. Parkes recommended the use of permanganate of potassium, which is the active ingredient in Condy's Fluid. The solution of permanganate should be added gradually and with constant stirring, until a very faint but permanent pink tint is perceptible. A little alum is then added, and the water allowed to clear by subsidence. Such waters also are improved in quality by being stored in well-charred casks. Very foul waters, when kept, often undergo a kind of fermentation, and become clear, bright, and palatable.

A method for sterilising potable water, of which an

abstract will be found in the *Journal of State Medicine*, vol. viii., p. 198, has been devised by the chief army surgeon of the Prussian army. The process is especially adapted for troops on the march or in camp, and consists in adding to the water a measured quantity of bromine dissolved in bromide of potassium, the bromine being subsequently fixed by the addition of alkaline bases. It was found that .06 gramme of free bromine was sufficient to sterilise a litre of water, and that after the bromine had been saturated with the corresponding quantity of ammonia, the taste of the water was hardly distinguishable from that of the original sample, and that so little of the bromine salt was present as to be without influence on the general health. The solution of bromine (Br 21.91, KBr 20, water to 100 grammes) was contained in sealed glass cylinders, each cylinder holding 22 c.c. It was found by experiment that each tube was capable of killing all the typhoid and cholera bacilli in about 67 litres of water, which had been artificially infected with these organisms. The alkaline mixture was in the form of a powder in corked tubes, each charged with twelve grammes. The formula of the mixture was Sodium Sulphite 7.2, Anhydrous Sodium Carbonate 3.0, and Mannite 1.8. This quantity of powder is enough to neutralise the bromine contained in one of the sealed glass cylinders.

Drs. Parkes and Rideal, in a paper read before the Epedemiological Society on Jan. 18th, 1901, recommend the use of tabloids of sodium bisulphate for destroying the bacillus of typhoid fever in water. They find that 15 grains of this salt added to one pint of infected water kills the bacillus in 15 minutes, and they express the opinion that the use of this salt would diminish the inevitable suffering of our soldiers from thirst and protect them from the ravages of water-borne disease.

CHAPTER XV.

THE SOFTENING OF HARD WATER.

As previously explained, the hardness of water is due to the presence of compounds of lime and magnesia, chiefly the former. The temporary hardness is due entirely to the carbonates of these bases, whilst the permanent hardness is caused by the sulphates, chlorides, and other salts. The disadvantages attending the use of hard waters have already been referred to, the chief being the waste of soap when the water is used for certain domestic purposes. With very hard waters this waste is so great that it is much more economical to soften the whole of a public supply than for each consumer to soften his quota by aid of soda or soap. From the description of the various processes in use for softening water, and their cost, the conditions which determine whether it is advisable to adopt one or other of them will be manifest.

Water may be softened—(*a*) by boiling; (*b*) by distillation; and (*c*) by the addition of lime, with or without carbonate of soda, soda ash, or other chemicals.

(*a*) By boiling, the carbonic acid gas is driven off, and the carbonates of lime and magnesia which had been held in solution by this gas are deposited. The process is troublesome and expensive. The Rivers Pollution Commissioners calculated that the fuel (coal) necessary to be used to soften 1,000 gallons of water by boiling for half-an-hour would cost about 7s. 6d. The same quantity of Thames water softened by soap would cost 9s., so that boiling is not much less expensive than softening by soap.

(*b*) Distillation naturally is much more expensive than simple boiling, and would never be resorted to simply for softening a water. Boiling merely removes the temporary hardness; distillation separates all the saline ingredients, so that distilled water is the softest of all waters.

(*c*) By the addition of lime. Lime has a great affinity for carbonic acid, combining therewith and forming carbonate of lime or chalk. When lime, therefore, is added to a natural water, the carbonic acid is absorbed, and the chalk previously held in solution thereby is precipitated, together with a portion of the carbonate of magnesia if any be present. The sulphates and chlorides are unaffected, so that the permanent hardness is not reduced. Care has to be taken that an excess of lime be not added, since it again increases the hardness. As 1 cwt. of lime, costing 1s., will soften as much water as 2 cwts. of 60 per cent. soda ash, costing 14s., or 1 ton of soap, costing over £30, there can be no question as to the economy of using lime. Dr. Clark was the original patentee of the lime process, and it is the one almost universally adopted. Since the lapse of his patent many modifications have been devised for the purpose of dosing the water automatically with the proper quantity of lime, and for facilitating the removal of the carbonates precipitated. Most of these are more especially designed for softening water for manufacturing purposes and for use in steam boilers, rather than for water for domestic use, but certain of them can be adapted for either purpose.

In Clark's original process lime water was added to the water to be treated, and the mixture was allowed to clear by subsidence in large tanks or reservoirs. To ensure complete clarification required at least 6 to 8 hours. Large tanks were necessary, and these had frequently to be cleansed.

Messrs. John Taylor, Sons, and Santo Crimp have kindly

furnished me with the following particulars of the process employed by the Colne Valley Water Company:—

This company derives its water from wells sunk in the chalk, and is at the present time supplying upwards of two millions of gallons per diem during the summer months. The whole of the water is softened by Clark's process. Buxton or other suitable lime is purchased, brought on to the works and tipped into a building marked on the accompanying diagram (Fig. 17) "Lime Slaking House." Quantities as required are placed in slaking trough and slaked, and afterwards water is added to bring the lime into the consistency of cream. This cream of lime is passed through a screen and allowed to gravitate into one or other of the "lime water tanks." The lime water tank is then filled with softened water and the liquid thoroughly agitated by means of air which is forced through pipes to the bottom of the tank by a special air pump. The liquid lime water is then allowed to rest and clarify; samples are extracted from the tank and tested for strength, and if the solution is not saturated further blowing with the air-pump takes place. After the lime water has thoroughly clarified it is run off by means of a floating pipe into one or other of the "softening tanks." The lime water tank is again filled with softened water, and the operations above described repeated. By means of decanting the clear liquid through the floating arm the impurities and unburnt portions of the lime accumulate in the bottom of the lime water tanks, and provision is made for cleaning out the tanks by means of a chain pump.

It will be seen from the diagram that there are 3 lime water tanks, and these are used in rotation; thus, while one is filling, a second is standing full for clarification, and the clear liquor in the third is being withdrawn into the softening tanks. The dimensions of each of these tanks are 32 feet long, 26 feet wide, and 19 feet 6 inches deep.

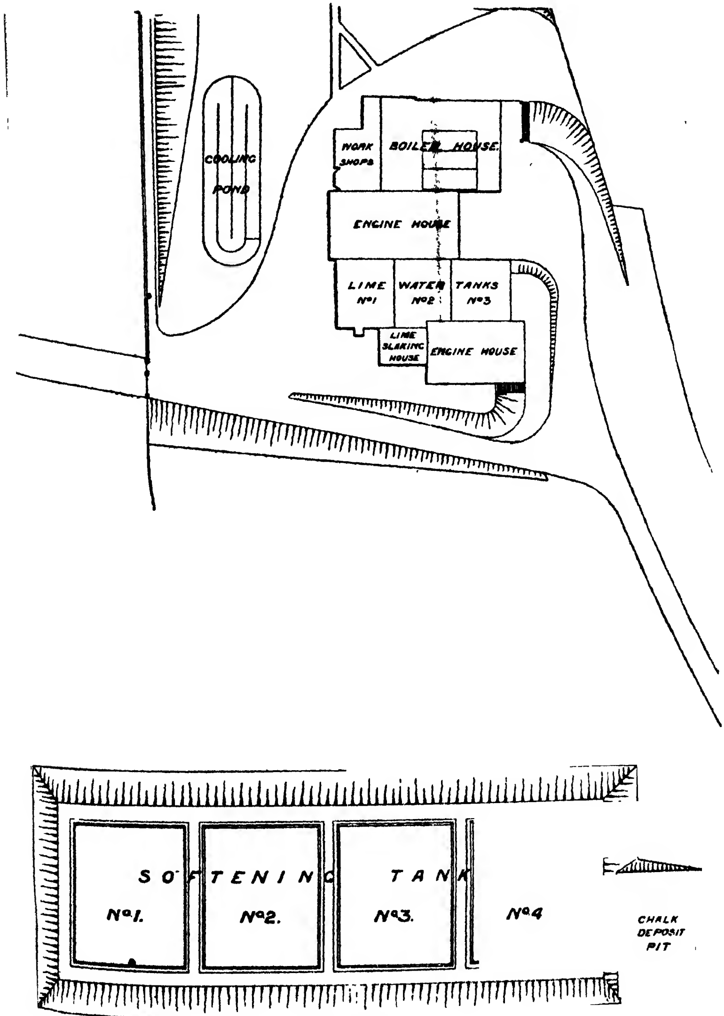
COOLING POND
WORK SHOPS
BOILER HOUSE.
ENGINE HOUSE
LIME No1
WATER No2
TANKS No3
LIME SLAKING HOUSE
ENGINE HOUSE
SOFTENING TANK
No.1.
No2.
No3.
No4
CHALK DEPOSIT PIT

FIG 17.

After the lime water has been decanted into one or other of the softening tanks, this tank is filled by means of the pumping machinery with the hard water, and the agitation due to the water entering the tank is sufficient to cause an intimate mixture with the lime water. Samples are tested from time to time as the filling of the softening tanks proceeds to ascertain when the lime water which was first added has entirely been utilised by the hard water which has been mixed with it, and when the action is complete, and no further free lime is present, the tank is shut off from the pumps and the liquid is allowed to stand for a few hours to allow the precipitated chalk to deposit. When this has taken place the clarified liquid is drawn off from the tanks by means of floating arms, and is pumped into the service reservoirs. When the liquid has been drawn down to within two or three feet of the bottom, the tank is shut off, a fresh quantity of lime water is admitted, and the operations proceed as described. There are 4 softening tanks, each tank being about 85 feet long, by 70 feet broad, by 18 feet in depth. The cycle of the 4 tanks in general working is—two standing full clarifying, one filling, and one being emptied after the water has been softened and clarified.

The exact amount of lime water to be added depends upon various circumstances, but in working practice it is found that with the particular water in question 10 per cent. of lime water effects the largest amount of softening. After the softening tanks have been in use for a few weeks there has accumulated from 2 to 3 feet of chalk deposit. The tank is then thrown out of use, and the chalk deposit is pumped into pits, where it is allowed to dry and accumulate.

Modern inventors have devised means for dispensing with the large settling tanks, and for ensuring much more rapid and complete removal of the precipitated carbonates. These processes all require a special plant.

In Atkins' process lime is mixed with water in a cylinder called the "lime cylinder," and the solution so formed passes through special regulating valves into a "mixer," in which it is mixed with the water to be treated in the proper proportion. The mixture then flows into a "softening cistern," in which a portion of the precipitated matter is deposited, and the partially clarified effluent is next conducted into patent machine filters, which "are constructed with a series of hollow metal discs, covered with cloth, so arranged as to give the largest possible amount of surface in the smallest space." Sets of spray pipes are attached in such a manner as to play over the whole surface of the discs when set in motion, and the filters are rapidly cleansed. At Henley (population 6,500) such an apparatus, with five filters, has been in use since 1882, and, according to Professor Attfield's analysis, the water is reduced by the treatment from 19.5° to 4.2° of hardness. At Southampton (population 79,000) about 3,500,000 gallons of water per day are softened, and the plant is said to be the largest in the world. It includes nineteen filters, a softening tank 76 feet by 45 feet by 5½ feet, four "lime" cylinders, mixer and lime-slacking mills, all comprised in one building measuring about 134 feet by 48 feet. Without enlarging the building additional plant can be added, so as to increase the supply of softened water to 5,000,000 gallons per day.* The cost of softening at Southampton is ¼d. per 1,000 gallons for working expenses and another ¼d. for interest and repayment of loans, making a total cost of ½d. per 1,000 gallons. At Lambeth workhouse, with 1,500

* Much dissatisfaction at one time arose at Southampton in consequence of the water, after being softened, depositing calcareous matter in the mains, and not always being delivered free from turbidity. Whilst, on the one side, this was declared to be the fault of the process employed and insufficiency of the filtering area, the patentees asserted that it was entirely due to the careless way in which the system was worked. Since additional filters have been provided, and the plant has been modified, excellent results have been obtained.

inmates, there is an installation for softening 300,000 gallons of water per day. The plant occupies a space of 22 feet by 16 feet, and the only attention required is said to be the labour of one man for an hour a day. The cost of the plant was about £2,000, and the total expense of treating the water supply is said not to exceed £50 per year, or, including interest on capital, about ½d. per 1,000 gallons. The saving in soap, soda, fuel for boilers, repairs to boilers, tea, etc., is believed to amount to over £1,000 per year.

The Porter-Clark Company claim that their system is the most economical, since the apparatus is of a very simple character, requires very little labour and attention, and works under pressure, so that the softened and filtered water can be delivered into high-pressure cisterns without pumping. It consists of two vertical cylinders and a filter press. In the first cylinder there is a continuous preparation of lime water. In the second the hard water and proper proportion of lime water are mixed, and in the press, which is made up of a series of plates, with cloths interposed, the precipitate formed is filtered out. Where large quantities of water are being treated, some motive power is required to keep the contents of both cylinders in a state of agitation. The approximate price of a plant softening, automatically, 1,000 gallons an hour, is £200; for softening 2,000 gallons, £280. The London and North-Western Railway Company use this system at various depôts. At Liverpool, Camden, Willesden, and Rugby, about 1,000,000 gallons, in all, are softened daily for use in their locomotives. Modified forms of this apparatus are made for special purposes. One form, which dispenses with motive power, save that of a man for a few minutes daily, will soften from 500 to 2,000 gallons of water per hour, and by the use of various other reagents besides lime, such as caustic soda and carbonate of soda, the permanent as well as the temporary hardness can be reduced where necessary. The Porter-Clark process has been adopted in

a large number of public institutions, manufactories, mansions, etc.

The "Stanhope" water softener (Fig. 18) occupies but little space, possesses no movable parts, and no filtering apparatus, the water being clarified by subsidence in special tanks containing numerous sloping shelves, upon which the carbonates are deposited. It aims at reducing both the permanent and temporary hardness, lime and soda being the chemicals used for this purpose. The only attendance required is that of a man to mix the lime-water and soda every few hours, and to open the mud cocks occasionally to let out the accumulated precipitate. The cost of softening by this process is stated by the makers to average 1d. per 1,000 gallons, though this will depend upon the character of the water treated. It appears to be a favourite with manufacturers, especially woolwashers and bleachers, and with large users of steam power for boiler purposes. Quite recently the Stanhope water softeners and purifiers have been considerably improved. For the sloping shelves in the clarifying tower a series of perforated funnel-shaped cones (Fig. 19) have been substituted. These cause the water to traverse the tower more slowly, and more perfect sedimentation results. A continuous mechanical lime mixer has also been added. For potable purposes some system of filtration is necessary to secure absolute clearness. The makers recommend filter presses, since the work left for the cloths to do is almost *nil*, and they may be used for a length of time without requiring cleaning. The natural head of water from the clarifying tower supplies all the pressure necessary. This simple mode of filtration may be sufficient for certain very pure waters, but for contaminated waters sand filtration would be far preferable.

The "Howatson" softener is somewhat similar in principle to the above. The lower portion of the apparatus consists of a tank divided into two compartments, each having a hopper bottom. Into one the water and chemicals

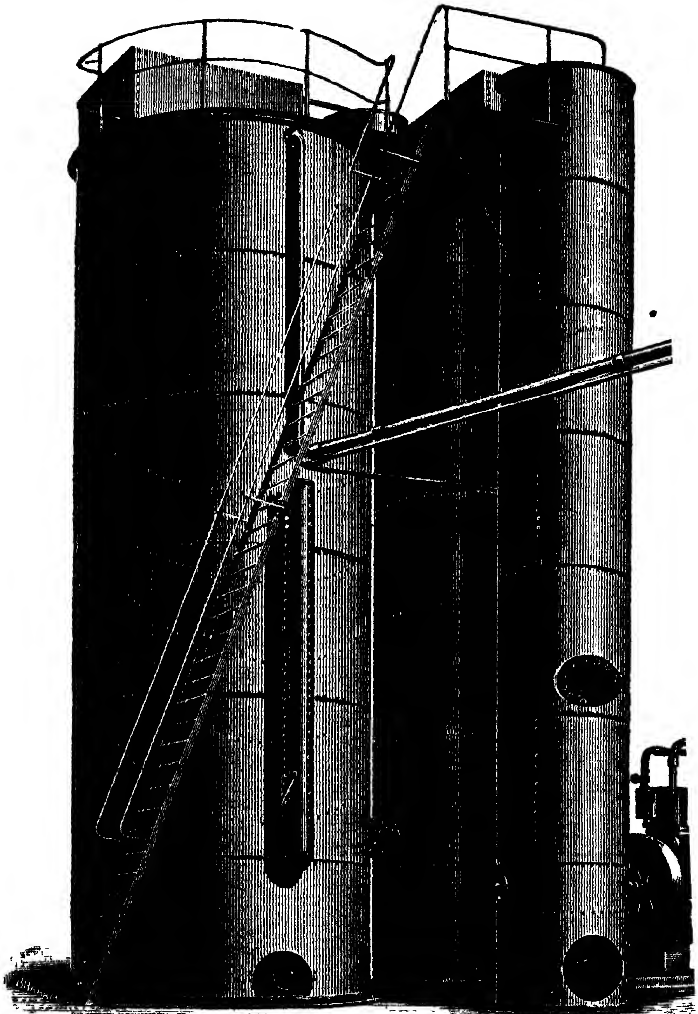

Fig. 18.—The "Stanhope" Water Softener.

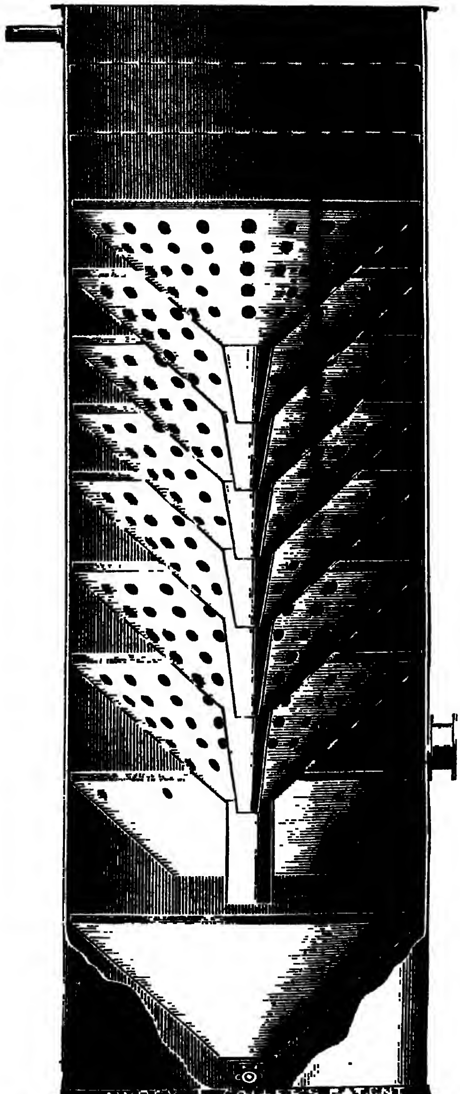

Fig. 19.—The "Stanhope" Water Softener (Clarifying Tower).

are introduced, and after chemical action has taken place the mixture passes at the bottom into the other, which acts as a "subsidence filter." The lime and other chemicals are contained in two smaller tanks placed above the larger, and which are used alternately. By means of floats, cocks, and nozzles, the portions of the chemical solution and of the hard water to be softened can be regulated. No agitator is required, and the deposited carbonates are removed by occasionally turning the sludge taps at the bottom of the hoppers.

At Stroud Waterworks the water is softened and clarified by a very simple modification of Clark's original process, all filtering machines being abandoned. By aid of a small water wheel, driven by the water to be treated, two pumps are worked, one raising lime water and the other the hard water. By altering the length of the stroke the proportion of the two can be adjusted, and as the rapidity with which the wheel rotates depends upon the pressure of the water in the mains, the relative quantities of lime water and hard water pumped remain constant. The treated water is clarified by subsidence in large settling tanks. The machine above referred to will soften 1,000,000 gallons of water per day, but the amount actually softened is only 300,000 gallons.

Messrs. Archbutt and Deeley have recently devised an apparatus which they regard as having many advantages over others in the market, especially for treating waters containing magnesia salts. The chemicals used (lime and soda ash) are boiled with water and then mixed with the hard water, contained in a tank, by means of a steam "trajector." After thorough mixing, steam and air are forced by a "blower" through perforations in a series of pipes laid close to the bottom of the tank. This stirs up the mud and diffuses it throughout the water, and when the liquid is allowed to rest precipitation is very rapid. In from thirty minutes to one hour the water is almost

perfectly clear and can be drawn off. By using duplicate tanks, one quantity of water can be treated whilst that in the other is undergoing clarification. Water which contains magnesia compounds, after precipitation, still contains a little carbonate of magnesia, which rapidly blocks up the boiler "injector." To obviate this the water, when being drawn off from the settling tank into the storage tank, is dosed with carbonic acid gas by aid of a blower. The carbonic acid is derived from the combustion of coke in a special stove. The water when sufficiently carbonated no longer deposits in the tubes. By this process the labour involved is no greater for softening 20,000 gallons than for 2,000, and with large quantities the expense for labour is said not to exceed ¼d. per 1,000 gallons. Some waters are found to clarify much more rapidly if a little alum be added, together with the other chemicals, and this the inventors recommend in such cases.

The cost for chemicals required to soften waters of various qualities is given in the following table by Messrs. Archbutt and Deeley, and is quoted here, since the chemicals used in this process are the same, both in quality and quantity, as those used in other processes which are designed to soften water containing both lime and magnesia. It will be observed that the cost increases rapidly with the amount of sulphates present, especially sulphate of magnesia, since such water can only be softened by use of soda ash as well as lime. In each case the hardness is reduced to from 3° to 5°.

The Maignen "Filtre Rapide" Co. are the makers of a plant which softens and filters the water automatically. By means of a small motor worked by the flow of the water to be softened, the proper amount of "Anti-calcaire" is added, and mixture takes place in a small tank. From this the water flows to another tank, where most of the sediment is deposited. Finally it traverses one of their rapid filters and reaches the storage tank in a completely

TABLE IX.

NUMBER	1	2	3	4	5	6	7	8	9
	GRAINS PER GALLON.								
Calcium Carbonate	8·74	13·15	16·39	10 99	9·19	2·06	9·41	8·34	1·39
Magnesium Carbonate	2·78	·33	·31	2·76	1·40	·94	1·00	2·82	1·78
Calcium Sulphate	3·26	...	4·30	2·99	12·17	47·34	22·91	40·61	54·14
Magnesium Sulphate	..	1·96	1·28	12·41	7·05	5·70	15·90	22·25	22·46
Magnesium Nitrate	...	...	...	..	13·69	...	11·50	...	...
Magnesium Chloride	...	...	...	...	·64	...	2·08	...	...
Total Solids	19·37	19·15	25·75	53·70	51·06	73·41	68·75	83·86	114·37
Total Lime (CaO)	6·24	7·36	10·95	7·39	10·16	20·64	14·70	21·39	23·07
Total Magnesia (MgO)	1·33	·81	·58	5·48	7·02	2·36	9·82	8·81	8·38
TOTAL HARDNESS (= *Calcium Carbonate equivalent to Total Lime and Magnesia*)	**14·5**	**15·16**	**20·99**	**26·77**	**35·53**	**42·7**	**50·57**	**60·02**	**61·95**
Cost of Chemicals required for softening 1,000 gallons	¾d.	½d.	1d.	2d.	3½d.	4¾d.	5d.	6d.	7d.

NOTE.—The above estimates of cost are based upon the following prices, *viz.* :—
Quicklime . . . . at £1 0s. 0d. per ton. | 58 per cent. Soda Ash . . at £6 17s. 6d. per ton.

clarified condition. This is one of the processes which can be used on the small scale, for private houses, etc.

Although certain of the processes described would appear to require very little personal attention, according to the statements of the inventors, yet, if uniformly satisfactory results are to be obtained, there must be constant supervision. The treated water must be repeatedly examined to ascertain that neither too little nor too much of the lime or other chemicals is being added. If too little, the water will not be properly softened, and if too much, the water will be rendered alkaline, and the magnesia will not be removed. When the amount of lime added is a little less than the theoretical quantity required to precipitate wholly the lime and magnesia salts, the two carbonates separate in a form which settles well, and the softened water filters readily. When the full theoretical amount is used, or a slight excess, the carbonates deposit slowly, and in a form which rapidly clogs the filters. Even after passing the filter, more magnesia continues to separate for from twelve to twenty-four hours. When spring or deep-well waters are being softened, the best proportions of lime water and spring or well water having been once determined, it only remains to examine the water occasionally to see that these proportions are being maintained, and that the lime water is uniform in strength. If the lime water be not saturated with lime it will be too weak, whereas, if by undue agitation it is not only saturated, but contains lime in suspension, it will be too strong. With river waters the case is often different. The composition may vary considerably with the season, and, if a tidal river, with the state of the tide, and skilled examinations must be frequently performed to ascertain the exact proportion of chemicals to be added.

The Rivers Pollution Commissioners state that at Canterbury, Caterham, and Tring, the water is reduced 20° in hardness by Clark's process, at a cost of only 27s. per

1,000,000 gallons for lime and labour. This may be taken as a fair estimate of the cost for lime and labour of softening an average sample of such hard waters as are being used for town supplies. Assuming that the interest of capital expended in plant, buildings, land, etc., increases the cost to 1d. per 1,000 gallons, or £4 3s. 4d. per 1,000,000, and that the hardness to be reduced is only 16°, the following may be taken as a low estimate of the saving effected by the softening of a town water supply—

Cost of softening 1,000,000 gallons	£4	3	4
Suppose $\frac{1}{10}$ only is used for washing purposes (domestic and laundry), and that half of this is softened with the cheapest soda, and the remainder with soap, the cost would be, very approximately	£60	0	0
Suppose $\frac{1}{10}$ be used in steam boilers, that steam coal costs 13s. per ton, and that 25 per cent. more fuel be used on account of incrustation, the cost of additional coal is	9	2	0
Total	£69	2	0

This represents a saving of nearly £65 per 1,000,000 gallons, or of £23,000 a year to a town of 30,000 population. A town of one-third the size would save £7,000. Even in very small towns the saving would be enormous. This estimate is very much below those usually given by makers of softening apparatus, and in many cases the cost of softening is said to be less than that given above, and a larger proportion of water may be used for washing purposes. They forget, however, that all the water used for washing purposes is not completely softened. When used for personal ablution only the very small quantity taken up on the hands is completely softened, as the water after use is found to be only 1 to 2 degrees softer than before. The saving in the wear and tear of boilers, of culinary utensils, and the saving in the consumption of tea, are also items

which have not been taken into account in the above estimate, yet which can be made to show a very considerable pecuniary balance in favour of softened water. Under the most adverse circumstances, where the water contains both lime and magnesia salts, and is "permanently" hard, requiring the use of soda as well as lime for softening, and large tanks and filter beds for ensuring complete clarification, the cost could not exceed 1s. per 1,000 gallons, and the saving effected would be actually greater than in the towns where the cost was only 1d., since the waste of soda, soap, fuel, etc., which would be prevented, would be so much greater in proportion.

The particular method of softening best adapted in any given case depends upon many circumstances, such as the character of the water to be softened, the purpose for which it is chiefly required, the amount of available space, the available motive power, the amount of water required, and whether for constant or occasional use. The cheapest plant, which, with the use of the cheapest chemicals, and the least expenditure in labour, will produce the desired result, will naturally be selected, and this can only be decided upon when all the above factors have been duly considered. Under suitable conditions all are capable of giving excellent results.

During the process of softening, the bacteria contained in the water suffer a considerable decrease in number. Apparently these organisms become entangled in the precipitate formed, and settle therewith to the bottom of the tanks. Professor P. Frankland found that by agitating water with powdered chalk, the treated water after subsidence only contained about 3 per cent. of the organisms originally present. A carefully-filtered softened water, therefore, ought to be practically sterile. With waters of a high degree of purity, the filtration necessary after softening would be merely to remove suspended particles of carbonates; but where river water, known to be sewage

contaminated, is being treated, the filtration must aim at removing all the micro-organisms which may have escaped precipitation, or have passed through the rapid filters supplied with certain of the machines—that is, this rough filtration must be supplemented by thorough filtration through properly-prepared sand filters. A water which has been thus treated would appear to be as safe for domestic purposes as our present scientific knowledge enables us to make it.

Mr. Kent makes a machine in which water is softened and partially sterilised by heat. The water flows through a coil of tube, heated by a gas flame, oil furnace, or other source of heat. The water at near boiling point trickles down a tube containing a series of metal discs, and upon these much of the lime salt is deposited. The incoming cold water cools the treated water. This process, though less troublesome, is much more expensive than softening by Clark's method.

CHAPTER XVI.

QUANTITY OF WATER REQUIRED FOR DOMESTIC AND OTHER PURPOSES.

THE amount of water necessary to supply all the wants of a given population may be calculated upon the basis of the theoretical requirements of each individual or household, plus the estimated quantity which will be necessary for municipal and manufacturing purposes, or it may be calculated upon the basis of the amount actually supplied to other similar communities. The results so obtained will often be found to vary considerably, and the causes of such variation are very difficult to explain. The amount used in households similarly circumstanced with reference to their supply varies greatly, according to the habits of the individual members; but where the supply is practically unlimited and readily available, the quantity used is always greatly in excess of that consumed where the supply is limited, or where it is more or less difficult to obtain. In rural districts, where water has to be purchased from the hawker or fetched from a considerable distance, the amount used is astonishingly small,—that which has been used for the purposes of personal ablution having often to serve afterwards for washing the crockery, and finally for washing the floors, etc. In numbers of cases I have found that the amount used in country cottages could not have greatly exceeded 1 gallon per person per day. Of course neither perfect cleanliness nor health is possible under such circumstances. On the other

hand, where the supply is abundant and easy of access, a very large proportion is often wasted, and 100 gallons or more per person per day may pass from the mains into the sewers.

The purposes for which water is required may be summarised as follows—(*a*) For drinking, either as water or made into such beverages as tea, coffee, and cocoa, and for cooking purposes; (*b*) for personal ablution, including baths; (*c*) for household washing, including cleansing and swilling of floors, yards, etc.; (*d*) for use in water-closets; (*e*) for the supply of horses, cattle, and washing of carriages; (*f*) for watering plants and gardens in the dry season; (*g*) for municipal purposes, cleansing streets, flushing sewers, extinguishing fires, etc.; and (*h*) for manufacturing and trade purposes. Where for municipal and manufacturing purposes, water can be more cheaply obtained from wells, streams, or other sources, obviously the public supply of pure water needs not be nearly so large as in towns where such sources are not available. Where subsoil water can readily be obtained from shallow wells, it may be utilised for many of the above purposes, especially for the stable and garden, and the demand upon the public supply be further curtailed. The amount of water required for each of the above purposes has been variously estimated. Professor Rankine, in his work on *Civil Engineering*, states as his opinion that 10 gallons per head should be allowed for domestic purposes, 10 gallons for municipal purposes, and 10 gallons for trade purposes in manufacturing towns. Most engineers, however, consider the estimate for municipal purposes to be too high, since in the majority of towns the amount used does not exceed 3 gallons per head. For trade purposes also Rankine's estimate is probably excessive, 7 gallons per head being a liberal allowance. Dr. Parkes * measured the water expended in

* Parkes' *Practical Hygiene.*

several cases; the following was the amount used by a man in the middle class, who may be taken as a fair type of a cleanly man belonging to a fairly clean household:—

	Gallons Daily per One Person.
Cooking	·75
Fluid as drink (water, tea, coffee)	·33
Ablution, including a daily sponge bath, which took $2\frac{1}{2}$ to 3 gallons	5·0
Share of utensil and house washing	3·0
Share of clothes (laundry) washing, estimated	3·0
	12·0

The above may be taken as a liberal estimate for domestic requirements applicable for most communities. Where water-closets are introduced, 2 to 6 gallons, according to the mode of flushing, must be allowed; for the supply of horses and cattle and use in garden 2 to 5 gallons; for municipal purposes 0 to 10 gallons, and for manufacturing purposes 0 to 10 gallons. Where the water is not required for trade or municipal purposes, a supply of from 16 to 23 gallons per head will suffice; but where the water is also wanted for cleansing streets, flushing sewers, supplying factories, etc., as much as 40 gallons may have to be provided. Allowing 2 gallons for unavoidable waste, we may take 18 gallons as the minimum and 42 as the maximum supply required by any community.

These figures may be checked by the actual amounts used in various towns. The Rivers Pollution Commissioners, in their Sixth Report, in discussing the question whether a constant or intermittent supply be the more economical, give two tables—one of the amount of water supplied per house in each of the seventy-one towns with a constant supply, and the other of twenty-four towns each having an intermittent supply. The following is a brief summary of the tables referred to:—

	Constant Supply.	Intermittent Supply.
No. of towns using not more than 50 galls. per house	3	1
No. of towns using over 50 and not more than 75 galls. per house	13	4
No. of towns using over 75 and not more than 100 galls. per house . . .	8	2
No. of towns using over 100 and not more than 150 galls. per house . . .	20	9
No. of towns using over 150 and not more than 200 galls. per house . . .	10	2
No. of towns using over 200 and not more than 300 galls. per house . . .	12	4
No. of towns using over 300 and not more than 400 galls. per house . . .	2	2
No. of towns using over 400 galls. per house	3	0

The mean daily supply per house in the seventy-one towns was 135 gallons, in the twenty-four towns 127 gallons. Taking five as the average number of persons per house, the mean daily supply under the constant system was 27 gallons, and under the intermittent system 25.4 gallons. In London, with an intermittent system of supply, the average per person was 40 gallons (204 per house).

The amount of water supplied per house under both systems varied enormously. With a constant supply Heywood and Middlesborough furnished the two extremes. At the former town, with 5,200 houses and 30 factories, only 20 gallons per house per day were consumed; at the latter, with 7,000 houses and 80 factories, the amount was 700 gallons, or thirty-five times as much. The quantity stated to be supplied to Heywood is probably erroneous, since the Heywood and Middleton Company is elsewhere mentioned as supplying 7,000 houses and 150 manufactories with 100 gallons per house daily. This latter amount is, however, only one-seventh that of the Middlesborough supply, and the difference is the more marked inasmuch as both places are supplied by private companies, and the latter in each instance are reported to have inspectors who

examine the taps and fittings to prevent waste. With an intermittent supply, Huddersfield, with its 8,500 houses and 600 factories, only used 49 gallons per house daily, whilst Berwick, with 1,150 houses and 7 factories, used 330 gallons per house. That these enormous differences depend more upon the amount wasted than upon the amount used for either domestic, municipal, or trade purposes is almost certain. The consideration of a few more modern statistics confirms this opinion.

In the following table the amount of water used daily per unit of population in a number of representative towns is given. Most of the figures are taken from recent reports of Medical Officers of Health or Water Companies.

Town.	Population.	Water Supplied per Head Daily.
Saffron Walden	6,108	11 gallons
Melrose	1,300	13 ,,
Bridlington	9,806	16 ,,
Halstead	6,100	17 ,,
Chepstow	3,387	15 to 16 ,,
East Ham	33,000	20 ,,
Atherstone	5,000	20 ,,
St. Austell	3,400	21 ,,
Chelmsford	11,079	23 ,,
Bristol	222,000	23 ,,
Bedford	28,023	25 ,,
Weston-super-Mare	15,869	26 ,,
Swansea	93,864	27 ,,
Barking	15,115	26 to 30 ,,
Nottingham	211,984	$28\frac{1}{2}$,,
Wolverhampton	82,620	29 ,,
Grantham	16,746	30 ,,
Yeovil	9,648	31 ,,
Walthamstow	49,400	36 ,,

The variations here, though not nearly so great as in the River Pollution Commissioners' table, are still very considerable. Having recently to make an examination of the Halstead supply, I verified the above figures. The supply

there is constant, and the water is used for flushing sewers, watering the streets, etc., as well as for flushing water-closets, and other domestic purposes. In this town a large proportion of the women is engaged during the week at the crape factories, and Saturday is the great washing-day. The amount used on a Saturday was as under:—

From 8 A.M. to 2 P.M.	. . .	9,800 gallons per hour
,, 2 P.M. to 4 P.M.	. . .	9,500 ,, ,,
,, 4 P.M. to 5 P.M.	. . .	6,000 ,, ,,

The average amount used on a week-day was 104,000 gallons, and on Sundays 84,000 gallons. Small as this amount appears, there is no doubt that a considerable portion was wasted, since many thousands of gallons passed from the service reservoir during the night, when little or none was being used.

At Wolverhampton the careful records kept at the Corporation Waterworks show that in 1868 "the domestic consumption per head of consumers, deducting for trade purposes, street watering, etc.," was 18 gallons. In 1892 it had increased to about 23 gallons. In the latter year the total amount supplied for all purposes was about 29 gallons per head daily.

At Newcastle the consumption per head, for all purposes, in 1863 was 28 gallons; in 1881 it had increased to $38\frac{1}{2}$ gallons. "This," says Dr. Armstrong, the Medical Officer of Health, "shows an increase of 37 per cent. in the amount consumed for each person, due, no doubt, largely to improved habits of cleanliness among the people. Looking at the fact that baths and water-closets, which even then were considered as luxuries, are now regarded as necessities in almost every house of any pretensions to comfort, . . . it is not too much to assume that there will be a still further increase in the consumption per head." No doubt this in a measure is true, but it is at least probable that much of this increased consumption is really

increased waste, consequent upon the increased age of the mains and fittings. In London, by greater attention to the sources of waste, the net supply per head of population has in many cases been very considerably decreased. The following table * is interesting as showing the actual amount of water supplied daily by the London Companies and the wide difference in the supply per head.

Name of Company.	Net Supply Daily.	Population.	Net Supply per Head.
New River	32,640,976	1,159,260	28·16
East London . . .	39,704,601	1,158,500	34·27
Chelsea	9,557,388	287,362	33·25
West Middlesex . . .	15,419,907	577,235	26·71
Grand Junction . . .	16,701,734	350,000	47·72
Lambeth	20,234,560	655,921	30·85
Southwark and Vauxhall .	24,373,348	841,989	28·94
Kent	12,530,891	460,524	27·21
	171,163,385	5,490,791	31·19

Of this quantity it is estimated that about 20 per cent., or between 6 and 7 gallons per head, is used for trade and municipal purposes. Whilst the West Middlesex Company supply only 27 gallons per head, the Grand Junction Company supply 48 gallons, and this the engineer of the latter company explained to be chiefly due to waste, since they found it cheaper to pump water than to supervise and control the waste.

The following table is taken from a paper by Mr. T. Duncanson, A.M.I.C.E., on "The Distribution of Water Supplies," read before the Liverpool Engineering Society, April, 1894.

* *Report of Royal Commission on Metropolitan Water Supply*, 1893.

Name of Company or Town.	Year.	Domestic Supply in Gallons per Head.	Trade and Public Supplies. Gallons per Head.	Total Gallons per Head.	Percentage of Supply. Given Constant
Liverpool . .	1893	17·10	9·8	26·9	100
Bradford . .	1891	18 to 20	20·0	38 to 40	100
Manchester . .	1893	15·0	9·0	24·0	100
Birmingham . .	1893	17·0	8·75	25·75	100
Glasgow . . .	1893	36·0	16·0	52·0	100
St. Helens . .	1893	18 to 21	18 to 20	36 to 41	100
Swansea . .	1893	23·4	4·2	27·6	32

All waste is included in the amount set down for domestic supply.

The amount of water supplied per head per day in many cities in the United States is enormous. The following figures are taken from Vol. xxxix. of the *Engineering Record* (p. 322). New York in 1870 used 82 gallons per head per day, in 1899 the amount had risen to 119 gallons. In Boston, in 1895, 90 gallons were supplied and used as under :—

For municipal purposes	5	gallons
For trade purposes	30	,,
For domestic use	40	,,
Unavoidable (?) waste	15	,,
	90	,,

In Philadelphia (*Engineering Record*, vol. xxxix., p. 430) no less than 230 gallons are supplied, but it is stated that half to two-thirds is recklessly wasted. On the other hand, certain continental cities have a much more limited supply than London. In Berlin, for example, the daily supply is said to be only 20.56 gallons per head per day, 20 per cent. being used for municipal purposes and 80 per cent. for domestic purposes.

Waste of water arises from two distinct groups of causes —(*a*) those over which the consumer has no control, and (*b*)

those under the control of the consumer. As a rule the latter causes are responsible for the larger portion of the waste. Under (*a*) are included leakages from faulty mains and service pipes, and all other hidden defects, where the water escapes unperceived into drains and sewers or into the subsoil; under (*b*) the waste from defective house fittings, leaving taps open, etc. Such waste is also supplemented by an unnecessarily great consumption, due to the use of imperfect appliances, such as many forms of closet basin, and flushing tanks, the automatic flushing of urinals, and to the use of water for gardens, fountains, and similar purposes.

By the employment of a staff of inspectors the waste arising under (*b*) may be in a great measure controlled, but something more is required for the discovery and check of that arising under (*a*). By the use of water-waste meters or detectors the particular branch mains from which the water is escaping can be discovered, and by the aid of an instrument resembling a large stethoscope the faults can be localised. The "Deacon," "Tyler," "Kennedy," and "Ginman" waste detectors are those best known. These meters register automatically and continuously the rate at which the water is passing through the mains to which they are attached. It can thus be ascertained whether the draught has been excessive at any particular time, or whether this is constantly high. The number of houses supplied through each meter being known, it is easy to decide whether the amount of water which has passed is in excess of their requirements. If, after an examination of the fittings and rectification of visible defects, waste still continues, the mains and service pipes require attention. If the ear be applied to the service pipes near where they emerge from the ground, any escape of water from the pipe or main in the immediate neighbourhood can be heard, the more distinctly the nearer the defect. The ear can also be applied to the uncovered main for a similar purpose, but it

is often more convenient to apply it indirectly, using a walking-stick or a special instrument. Upon placing one end on the exposed main and the other to the ear, the fault, if any, can be localised. I am informed that an experienced man can during the quiet hours of the night detect defects by listening with this instrument in contact with the ground over the mains.

Mr. E. Collins, M.I.C.E., in a paper recently read before the Institution of Civil Engineers, on "The Prevention and Detection of Waste of Water," says that a 4-inch Deacon's meter will control 400 to 500 houses, but that smaller districts are preferable. The outlay involved is considerable, averaging £150 for each 1,000 houses controlled. This sum includes the cost of the meters and of fixing them on a by-pass, and of the valves necessary for isolating the divisions of the district. Where the meters are in use, however, a much smaller staff of inspectors is necessary, since a glance at the meters enables the inspector to discover the locality in which waste is taking place. At Shoreditch, as previously mentioned, Mr. Collins was able in three years to so reduce the waste as to save annually 720,000,000 gallons of water. This was effected by a capital outlay of £1,800, and an annual expenditure of £926 for staff and establishmental expenses. Each 1,000,000 gallons saved cost therefore about £1 9s. Small as this sum appears, it is probable that it exceeds the cost of pumping, especially if the most modern machinery be employed. The prevention of waste can only be accomplished by the expenditure of money, and whether it be more economical to allow the waste to continue or to control it depends upon circumstances varying from place to place, and it is only after a careful consideration of these that it can be determined in any given district which is the cheaper.

When inquiries are made to ascertain the cause of the variation in the amount supplied in different towns, it is found that only on the assumption that it is due to the

varying quantity wasted can an explanation be offered. Some towns, with manufactories using large quantities of water, use less in proportion to the population than others in which there are few or no manufactories. Towns in which there are very few water-closets often use more than towns in which water-closets are universal. Where the closets are chiefly flushed by hand more water may be used than where all have got a supply laid on. Where no water is used for sewer cleansing more is often used than where flushing arrangements are fixed at the end of every sewer. Where water from the mains is used for street cleansing and road watering, less is often actually used than in towns which obtain water for these purposes from other sources. In every town, moreover, there is a great outcry about the amount wasted, and we can only conclude therefore that since no other factor or combination of factors will explain the difference in the amount supplied per head daily, that this must be attributed chiefly to waste. Such being the case it is evident that the amount of water necessary for the supply of a town is very much less than the estimates given. Probably 20 gallons per head daily would be an abundant supply for all purposes in the majority of cases, and 30 gallons only be required in exceptional instances. To prevent waste and unnecessary consumption, however, so that the above quantities may suffice, the whole of the works in the first instance would have to be most carefully constructed, means taken to quickly detect where waste is occurring, constant supervision exercised over all house fittings, and all undue consumption checked by byelaws, or by insisting upon the use of water meters by large consumers.

Few persons realise the immense amount of water which is wasted in almost every town. Thus in Liverpool, where the average amount supplied daily per head was 33.5 gallons, Deacon's water-waste detectors were introduced, and these, together with efficient inspection, reduced the

supply to 23 gallons without any restrictions being placed upon the consumers. At Shoreditch, with a population of 87,000, the introduction of waste detectors effected in the course of three years a diminution of waste and undue consumption amounting to 720,000,000 gallons per annum, or 23 gallons per head daily. Mr. Boulnois recommended the use of Deacon's meters at Exeter, and their introduction reduced the waste from 75 to 12 gallons per head per day.

In other parts of London, in Bradford and elsewhere, where waste detectors have been introduced, the expenditure of water has been reduced by from one-third to one-half.

A most instructive instance of what can be done by checking waste was given by Mr. Hawksley in evidence before the River Pollution Commission. He said that when "the city of Norwich Waterworks were transferred from a very old-fashioned company to a new one . . . the delivery amounted to 40 gallons per head per diem, and that amount of consumption exhausted all their pumping power. They obtained a very good manager, and, under my advice, they applied for an additional Act of Parliament to enable them to correct the fittings. . . . The bill was carried, and it was put into operation, and now and for many years past, although the constant supply has been unfailingly in use, the water is never shut off, and the consumption has descended to 15 gallons per head per diem, as compared with 40 previously." In many cases a check is placed upon waste by placing in the service pipe leading to the house cistern a disc with a small hole in it, which prevents more than a certain amount of water passing through in a day. This, however, is a most objectionable arrangement, and quite unnecessary, since better results are obtained by adopting regulations as to the strength, proportion, and quality of the fittings, and enforcing the regulations.

In America water meters are being largely used to prevent waste, and with great advantage. For example, in Milwaukee before meters were generally adopted the water used per tap was 1,781 gallons per day. Now, when the great majority of houses are furnished with meters, the amount used per tap is only 644 gallons.

In tropical climates, doubtless, the demand for water is greater, and probably even 30 gallons per head per day would be barely sufficient. In Bombay 40 gallons is supplied, and in Calcutta 35.4 gallons of filtered water and 8.9 gallons of unfiltered, total 44.3 gallons; but in many other cities the amount used falls far short of this. In Madras, for instance, only about 18 gallons is supplied; but this is very probably far too little for all the requirements of the population.

The amount of water required by various animals naturally varies, chiefly with the size. Cavalry horses are allowed 8 gallons, and artillery horses 10 gallons per day. Elephants require at least 25 gallons, camels 10 gallons, and oxen 6 gallons per head daily.

By a careful study of the requirements of any community the amount of water which must be supplied daily may be estimated with a fair approach to accuracy; but whilst every care is taken to avoid waste, it must be remembered that this cannot be entirely prevented, and that it is far wiser to provide a supply in excess of the requirements, so as to be prepared for contingencies, and for a possible increase in the demand, from growth of population and other causes.

The amount of water used per week throughout the year does not vary greatly, but, as a rule, more water passes through the mains in summer than in winter. In Liverpool, during 1893,* the maximum consumption took place in the week ending 8th July, and was about 15 per cent. above the average, and the minimum during March,

* Duncanson, *loc. cit.*

November, and December, and was about 9 per cent. below the average. (*Vide* Chapter XXI.)

In small towns and rural districts where a large number of houses have gardens attached, the summer consumption of water is often greatly in excess of that used in winter. The most stringently enforced regulations often fail to prevent water being used in excess for gardening purposes during seasons of drought, and such misuse of the water by persons living in the lower portions of a district may deprive those residing upon higher ground of the supply to which they have an equal right.

CHAPTER XVII.

SELECTION OF SOURCES OF WATER SUPPLY AND AMOUNT AVAILABLE FROM DIFFERENT SOURCES.

Where there is only one source of water available there is no question of selection, since there is no choice. Such instances, however, are comparatively rare: usually there are more sources than one from which water can be obtained; and in deciding upon one or another many points have to be considered. A water seriously contaminated with sewage or intermittently liable to such contamination, water containing mineral matter in excessive quantity or of deleterious quality, and water with any marked odour or colour, would naturally be at once rejected. *Cœteris paribus*, the water of greatest hygienic purity and best adapted for manufacturing purposes would be selected. Where the available quantity or economy in utilisation, or both, are in favour of a water from a certain source, the importance of these factors must not be allowed to outweigh those of purity and freedom from risk. As the characteristics of good drinking waters and the dangers attendant upon the use of polluted waters have already been discussed, it is not necessary to do more than refer to them here, special attention being directed to the sections dealing with river water, the self-purification of rivers, and the discussion of the risks involved in the utilisation of river waters admittedly polluted, even when the intake is many miles below the source of pollution and the filtration is conducted according to most modern methods. Where

towns of any magnitude are concerned, the subject is so important that the services of experts—engineering, medical, and chemical—would naturally be enlisted; and by these all the advantages and disadvantages of the different available sources would be carefully considered, and the decision arrived at would be based upon the facts recorded and the opinions expressed in their reports. The nature of much of this evidence may be inferred from the sections treating of the quantity and quality of water obtainable from various sources, since the information there given is of general application. The estimates of cost of collecting, storing, and distributing will vary in each individual case, and certain points bearing upon these questions will now be briefly considered.

In the first instance, however, it will be better to consider the simplest case—that of providing a supply of water for a single house or small group of houses. In this, as in undertakings of greater magnitude, some knowledge of the geology of the district is in most cases absolutely necessary. Without this the search for underground water is mere groping in the dark, which may or may not be successful. Where a spring, however, is available, doubtless this will be at once selected, especially if it arises at such an elevation as to be capable of supplying the house or houses by gravitation. In examining any district for the discovery of springs, the sides of all streams should be carefully examined, and all tributary rivulets should be followed up to their respective sources. If the flow of the stream appears to be considerably augmented at any point, it is probably due to the influx of water from a spring, which may permit of being tapped above the point of discharge. In this case the construction of a reservoir large enough to hold at least a day's supply and the laying of a service main is all that is required. One great mistake is, however, frequently made in this simple arrangement. The pipe is rarely of sufficient size, and sometimes

is not of suitable material. Galvanised iron pipe of 1 inch or even less diameter is often employed to convey water considerable distances. If the water contains little or no carbonate of lime, the zinc will almost certainly be dissolved and contaminate the water. The pipe then becomes coated with a deposit of iron oxide, which tends continually to increase, and ultimately the calibre of the tube becomes too small to convey the required quantity of water. I have known many cases in which such pipes have had to be taken up and larger ones substituted. Cast-iron pipes coated inside with Angus Smith's protective varnish should be used, and the diameter should never be less than 2 inches. Where water is required for fire-extinguishing purposes also, the diameter of the pipe must be considerably greater, and the reservoir must be much larger. The size of main required under different circumstances will be discussed when the "distribution of water" is being considered.

The character of the water yielded by springs from different geological formations has been discussed in Chapter V., and the variable yield from certain springs have also been referred to. Before attempting to utilise any spring as a source of water supply evidence should be obtained proving that even after periods of continued drought the yield is sufficient for the purposes required. Many springs which flow freely in the late winter, spring, and summer fail completely in the autumn, or at least yield a greatly diminished supply. The evidence of people who may have used the spring or observed the flow for many years will have some weight, but must not be too implicitly relied upon. The flow should be gauged from time to time and the effect of the rainfall ascertained, bearing in mind that the flow may not be affected by even long continued heavy rains until after the lapse of some months, and that the effect of a long continued drought may not be observed until long after it has passed away.

The less variable the flow, the more likely is it to be constant; the longer the interval between a heavy rainfall or a drought and the production of any effect upon the flow, the less likely is such an effect to be serious. As a rule land springs flow most copiously in February and March, and are lowest in October and November. The gaugings therefore in the autumn and early winter are the most important, since the minimum flow is the information required. If the character of the previous summer be also taken into account reliable inferences may be drawn from the results. Small springs may be gauged by ascertaining the number of seconds required to fill a bucket of known capacity, or better still by employing a large vessel, such as a tank or tub. Or the water may be caused to flow along an open channel, or trough, when the cross section and velocity of the water in the trough can be ascertained, and an approximate estimate of the flow easily calculated Larger springs may be gauged by damming up the water and allowing it to discharge over a board from which a rectangular notch has been cut. The notch should be two or more inches wide and the edges chamfered. The principle involved is the same as that already described for gauging streams, and the height of the horizontal surface of the water behind the dam above the lip of the notch being measured, the flow can be ascertained from the formula there given. The following table gives the discharge in gallons per minute and per day over a notch-board for each inch of width, and for varying differences of level. The quantity given in the table, multiplied by the width of the notch used, in inches, will give the yield of the spring at the time of gauging. With notches exceeding 3 inches in width the results may be relied upon; with narrower notches they are not quite so reliable. Moreover, where the flow is so small that a notch of less than 3 inches is required, the simpler plan of actual measurement is much preferable.

Depth.	Flow per Minute.	Flow per Day.	Depth.	Flow per Minute.	Flow per Day.
	·31	446	2½	9·8	14,112
	·88	1,267	3	12·9	18,576
	1·62	2,333	3½	16·3	23,472
	2·50	3,800	4	19·9	28,656
	3·48	5,011	4½	23·8	34,272
	4·57	6,580	5	27·8	40,032
	5·76	8,294	5½	32·1	46,224
	7·0	10,080	6	36·6	52,704

It is a noteworthy fact that although springs are not abundant on the chalk formation, yet some of the largest springs in the country arise in the chalk.

Where a spring is not available attention will probably be next directed to the subsoil as a convenient source of supply, in which case a slight knowledge of the geology of the district may be invaluable. The points to which attention must be directed have been referred to in the chapter treating of "subsoil water." The character of the strata within reach being known, and the directions in which they dip and the depth and position of the nearest wells having been ascertained, the presence or absence of water at any particular spot may usually be predicted, as well as the depth at which it will be reached. Where the subsoil is permeable and the water held up by an impervious stratum beneath, depressions in the ground, and spots upon which herbage is most abundant or appears greenest, will often indicate where the water most nearly approaches the surface. At sunrise and sunset films of vapour (mist) usually arise first over the damper portions of an area, and continue of greater density there than elsewhere. "On a dry sandy plain, morning mists or swarms of insects are said sometimes to mark water below" (Parkes). Near streams and near the coast water is generally found at a slight depth. This is the subsoil water flowing towards its natural outlet. Near the sea, however, the

wells may and often do yield brackish water. Even when some considerable distance from the coast, the continued maintenance of a low level in the well may result in the water becoming saline. During a recent exceptionally dry season, the water in a well supplying a town on the coast was markedly affected, although the well was 1½ miles from the shore. The chlorine, which is normally about 3 grains per gallon, gradually increased, until a maximum of 18 was reached. In hilly districts water is most likely to be found in the lowest portions of the valleys. Where the water-bearing stratum is covered with an impervious one, the search for water is much more difficult, but a careful study of the local geology, to ascertain the dip of the various strata and the thickness of those lying above the water-bearing rock, will usually lead to reliable inferences being drawn. This is not invariably the case, however. Thus in Essex a considerable portion of the London clay is capped with drifts of sand and gravel and boulder clay. The sand and gravel lying between the London and the boulder clay varies in thickness, and in some places is entirely absent, and it is often impossible to predict whether, by sinking at any particular spot, water will be found or not. This uncertainty has led to "water-finders" being employed, and as there is a pretty general belief in the powers of the hazel-twig in the district, it would appear as if the finders were usually successful. I have paid some attention to this subject lately, and find that from the manner in which the hazel-twig is held, by imperceptible muscular movements it can be made to rotate between the hands. I have seen the water-finder walk over places where water existed in abundance without the twig indicating its proximity. In localities which have been traversed by the finder, I have usually found that there was no difficulty in indicating where water could be obtained without the use of a hazel-twig. In one instance the hazel-twig gave strong indications of the presence of

water at a point at which I was certain there could be no water within 300 feet, since the soil was of clay; and in that particular district it was known to be 300 feet in thickness. The owner of the land, however, had every confidence in the water-finder and proceeded to dig a well. When he had penetrated the clay to a depth of about 100 feet and found no indication of water, his confidence vanished, and the work was abandoned. A gentleman with whom I am acquainted contends that the hazel-twig in his hands gives reliable information. He believes that the presence of the water affects him personally, and the twig through him. Twigs of other trees do not answer, since they do not possess the necessary elasticity, and cannot be made to rotate nearly so readily as the hazel. He has certainly, recently, been able to indicate the presence of water in unsuspected places, and as in his case there can be no suspicion of intentional deception, the result must either be due to accident plus unconscious cerebration, or to some, at present, inexplicable influence of water upon himself or the twig. A recent success was recounted in a letter which he addressed to me on 19th May, 1894. He says, "General ——— asked me if I would give my opinion upon the practicability of finding water in a field facing his house. I went over and marked out two spots, and at each of these places digging was commenced, and at less than 10 feet from the surface water was found. . . . I should add that some time since an engineer made experiments upon the same ground with boring apparatus, but gave it as his opinion that within the area no water was available." According to the geological drift map, the parish in which General ——— resides is partly on London clay, partly on gravel, and partly on boulder clay capping the gravel, and it would seem an easy matter to indicate almost the exact limits of the area in which water could be found. In justice to my friend, however, I must add that he knew nothing of the geology of the district.

Certain points requiring attention in selecting the site for a well are referred to in Chapter IV., and the possible effect of the pollution of the drainage area of the well, and the dimensions of this area, are discussed in Chapter XI. Before works of any magnitude are undertaken for utilising subsoil water, the area of the collecting surface should be ascertained, its configuration, etc., considered, and the depth of the ground water and the extent of its fluctuations determined. The less the fluctuation the more likely is the supply to be permanent, and the less the liability to contamination. Rapid fluctuations usually indicate variation in quality, as well as quantity, of the available water. Where limited amounts only are required, and the possibility of finding water or of determining the quantity available cannot be inferred, from the absence of similar wells in the vicinity, trial borings or sinkings must be made. The character of the strata penetrated must be noticed, and the boring continued until water is found or an impervious stratum reached. Into the latter it is unnecessary to bore unless it is believed to be of but slight thickness, and the water above it is not sufficiently abundant. Thin beds of clay are sometimes found in thick gravel drifts, and they hold up a certain amount of water, which is obtainable by pumping. When the clay is penetrated, the gravel beneath may not be fully charged with water, in which case that found above will run through and be lost. This is the explanation of the mysterious disappearance of water from certain wells which have been deepened to increase the supply or the storage capacity. Instead of the supply being increased, the limited amount previously obtainable has been lost, and the work has either been abandoned or an attempt made to reach the water, if any, held in the lower pervious layer. Where no impervious stratum is penetrated, the water when reached will not begin to rise in the bore hole, or

only to a very slight extent, since it is not under pressure. In deep wells, which will be considered later, as soon as the water-bearing rocks are reached, the water begins to rise, more or less rapidly, and may even overflow at the surface. In sinking shallow wells the trial bore must be continued until the depth of water is judged sufficient. By pumping the water out of the bore hole and noting the time required for it to again ascend to its former level, the abundance or otherwise of the supply may be judged,—the more rapid the rise the greater the available amount of water. The yield of a well is often gauged by the length of time required for it to fill to its normal level after being pumped dry. The depth of water and the diameter of the well being also known, the yield is easily calculated. The result so obtained is always too low, since the rapidity with which the water enters varies with the square root of the head, and the head varies with the difference between the level of the subsoil water and the level of the water surface in the well. A more accurate result therefore is obtainable by starting with the water at a conveniently low level (say at half the usual depth), and ascertaining the amount which must be pumped in a given time in order to maintain it at this level. Such experiments only indicate the amount available at that particular time, but if made after a long drought, the result will probably indicate the minimum yield of the well.

Many attempts have been made to devise formulæ for calculating the yield of water from wells and galleries (*vide* Frühling's *Handbuch der Ingenieurwissenschafen*). Certain of these have been discussed by Fuertes (*Engineering Record*, vol. xxxix., p. 28). The following is given for calculating the yield from a well sunk in a sandy or gravelly subsoil:—

$$Q = 3{\cdot}142X\,(H^2 - h^2) \div \text{natural log. } (2R \div d),$$

where

Q = the yield in gallons per second.
H = depth of water in well, at rest, in feet.
R = radius of zone of depression.
h = depth after pumping in feet.
d = diameter in feet.
X = PV, where P = the percentage of void in the sand or gravel (usually 30 to 40 per cent.) and V = the coefficient of velocity of flow of water in the gravel = about ·29 times the square of the effective size of the sand or gravel in millimetres.

Obviously there are so many factors which cannot be determined with certainty that such a formula can have little value.

Where the limited space available necessitates the well being sunk near drains, sewers, cesspools, or other similar possible sources of pollution, not only should every care be taken in the construction of the well, drains, sewers etc., to avoid contamination of the water supply, but the risk should be reduced to a minimum by sinking the well in such position that the flow of the subsoil water shall be from the well towards the drains, and not from the drains towards the well. In villages and on farms the ground water is usually so polluted as not to afford a safe supply, however carefully constructed the well. Good water can, in some cases, be obtained at a little distance away in the direction of the higher ground-water level. This distance will vary in different places according to the porosity of the subsoil, slope of the ground water, and amount of water to be pumped. Where water is only pumped in small quantities at a time, the influence of the pumping will extend but a short distance from the well; but where a supply tank or water butt has to be filled from time to time, the level of the water in the well may be considerably depressed and the drainage area be greatly extended (*vide* Chap. XVIII.). According to the permeability of the subsoil, the area capable of being drained

by the well will vary in diameter from 15 to 160 times the normal depth of water in the well. In a loamy soil a distance of 20 times this depth may be sufficient for safety; in very coarse gravel the distance should be 150 times the depth. Where the slope of the ground water is steep there might be safety within these limits, as the influence of the pumping would not be nearly so marked at the side of lower water-level; but as the plane of saturation is usually nearly horizontal it is best to err on the side of safety and regard it always as such. Whether the water should be obtained by sinking an ordinary well or by driving a tube well, may be decided after considering the advantages and disadvantages and relative cost of the different kinds of well as described in Chapter XX., on "Well Construction."

Where springs are not available, and water is not obtainable from the subsoil, the possibility of obtaining a supply from a deep well may be considered. As this is a somewhat serious undertaking, probably attention had better be directed in the next place to the supply which can be obtained directly from the rainfall. It is agreed that about half the rain which falls upon the roof or similar impervious surface during the whole year can be collected. The other half is lost by evaporation and by waste from the separators and filters. Why should not this rain water be stored and utilised? Even where water is obtainable for drinking purposes from springs or wells, it may be so hard or so limited in amount that it is desirable to collect the rain water for use in the laundry and for personal ablution. A fair-sized mansion has often a roof area sufficiently large to collect enough rain water for drinking, cooking, and general domestic purposes. Assuming the area covered by the roof to be $\frac{1}{4}$ of an acre (1,210 sq. yards), and the minimum rainfall 20 inches, then 10 inches of this may be collected. As a fall of 1 inch upon an acre represents 22,620 gallons, 10 inches upon $\frac{1}{4}$ of an acre represents

56,550 gallons for the year, or 155 gallons per day, a supply which would suffice for ten persons, allowing 15 gallons per head, or for 15 persons at 10 gallons per head. In most parts of the country the minimum rainfall reaches 25 inches, therefore admitting of a more abundant supply. Where the roof surface is not sufficiently large it has been proposed to prepare a plot of ground for the purpose. The best method of collecting, storing, and utilising rain water was discussed when treating of rain water as a source of supply (Chap. II.), and that section must be consulted for further details.

Where larger quantities of water are required, as for villages and towns, it may be derived from the rainfall on natural gathering grounds, from the subsoil, from springs, from deep wells, or from streams. Water collected in hilly districts from uncultivated surfaces, forms, as we have already seen, one of the best and purest supplies obtainable. A large number of towns in this country are supplied from such sources. Unfortunately in several instances the amount of water obtainable in the area of the watersheds has been over-estimated the result being that in exceptionally dry seasons something like a water famine has occurred. The approximate determination of the amount of water which can be collected from the surface over a given area is one of the most difficult problems in water engineering, since it depends upon so many factors, some of which (the meteorological conditions) are so variable as almost to defy our efforts to predicate their possibilities. Upon these meteorological conditions, so variable in themselves, depend in a very great measure two other factors—the loss by evaporation and by percolation. The only factors which are uninfluenced by the weather are the area, configuration, and character of the collecting surface. The 6-inch ordnance maps give the contour lines or lines of equal altitude drawn at every 25 feet. The ridge or watershed lines are also marked, and

from these the ground slopes downwards on both sides. These lines are continuous, save on the side which forms the natural outlet of the water collected in the enclosed area of gathering ground, technically known as a "drainage area" or "catchment basin." In one such catchment basin, branching ridge lines may form two or more secondary drainage areas. The area from which the water is to be collected may either be ascertained by actual measurement or be calculated from an ordnance map. The configuration, character of the surface and of the subsoil, and nature and amount of vegetation, require careful examination, since they influence greatly not only the amount of rainfall which percolates, but also the amount of loss by evaporation. A portion of the water which penetrates the ground in one part of the area may reappear in another part as springs, or it may be that the springs fed by the ground water lie entirely outside the boundary of the watershed, in which case a further portion of the rainfall escapes collection.

Where the hills are steepest, the rocks hardest, barest, and most impermeable, the loss both from evaporation and percolation will be smallest. The more permeable the subsoil, the more abundant the vegetation and the less steep the slopes, the greater will be the loss by evaporation and absorption. Where the soil is peaty, where moss abounds and bogs are extensive, much water is retained; it neither runs off the surface nor percolates into the subsoil, but is slowly lost again by evaporation. The loss by percolation is greatest where the subsoil is very porous—as when it consists of sand and gravel—and when the outlet for the ground water is outside the collecting area. However, as a rule, the localities selected as gathering grounds for water supplies have but a small proportion of their areas covered with any depth of permeable subsoil, since such ground is objectionable, not only because of the amount of water which it permits to percolate, but because,

in this country at least, it would be cultivated or used for pasturing cattle, and would therefore tend to pollute the water. The amount of water which may be lost by percolation has been referred to in Chapter IV. Both this and the loss by evaporation are affected greatly by the character of the rainfall. If the rain descends in frequent slight showers, the whole may be lost; whereas if the same amount falls in a few heavy downpours, a large proportion will run off the surface and may be collected. In the hilly districts selected as gathering grounds the rainfall is not only usually more abundant than in the plains, but it descends in sharper, heavier showers. As the water collected from any given area would otherwise have found its way into some stream or formed the natural source of such stream, the problem of ascertaining the amount of water which can be collected is frequently the same as that of determining the amount of water available from a stream. These we have already considered in Chapter VII., under the heads of (*a*) area of watershed, (*b*) the topography and geological character of the ground, (*c*) the average rainfall and the rainfall during a consecutive series of dry years, (*d*) the seasonal distribution of the rainfall, (*e*) the amount of water which must be supplied for "compensation" purposes, and (*f*) the facilities for obtaining storage. Based upon this knowledge engineers have devised formulæ for estimating the probable daily yield of a catchment area. Dr. Pole's formula is—

$$Q = 62A\left(\tfrac{4}{5}\,Rm - E\right).$$

In this equation Rm represents the average rainfall of a long series of years, and $\tfrac{4}{5}\,Rm$ the estimated average of the three driest consecutive years. E = the loss of rainfall by evaporation, percolation, and unavoidable waste; and A = the area of the gathering ground in acres. As 1 inch of rainfall upon 1 acre represents 22,620 gallons of water,

the average amount of water which can be collected yearly during the three driest consecutive years would be

$$22{,}620A \times (\tfrac{4}{5}\ Rm - E).$$

Since 22,620 divided by 365 is approximately 62, Pole's formula gives the mean daily yield of water from the catchment area. The importance of the factor E is evident, and it is to the fact that this has been occasionally underestimated that the scarcity of water in certain towns during long-continued periods of low rainfall is chiefly attributable. In some cases, however, the fault has been due to the reservoirs not having been sufficiently capacious to allow of the accumulation of an ample reserve to tide over such periods of drought. Under any circumstances the most capacious reservoirs may become filled, and rain continue to descend and pass down the bye-wash and be wasted. This unavoidable loss Mr. Hawksley estimates at one-sixth of the rainfall. The loss by evaporation and percolation—which, as we have seen, depends upon so many factors—is variously estimated by engineers who have studied this subject. Mr. Hawksley found at Sheffield that it was nearly 15 inches, "although the ground is very elevated, ascending to 1,500 or 1,600 feet; but it lies rather with a southern aspect, and the ground is mossy, and a good deal of water is held superficially, and of course is re-evaporated." In this country the loss by evaporation and percolation is given by the following authorities as under:—

Mr. T. Hawkesley,	11 to 18 ins.	Average 14 ins.
Dr. Pole,	12 to 18 ins.	
Mr. Humber,	9 to 19 ins.	Average 13 to 14 ins.
Mr. Bateman,	9 to 16 ins.	

Over most favourable areas, therefore, the loss may not exceed 9 inches, whereas over the most unfavourable ones which are likely to be selected as gathering grounds it may be as high as 19 inches. The value of E in Dr. Pole's for-

mula, therefore, will vary from $\frac{Rm}{6} + 9$, to $\frac{Rm}{6} + 19$, $\frac{Rm}{6}$ being the unavoidable waste.

The amount of storage necessary to render the required amount of water available during the longest drought varies considerably in different places. Where the rainfall is heaviest the storage necessary is least, and *vice versâ*. Over the western half of this country, and in the more mountainous districts, 120 days' storage has been found sufficient, but in the eastern counties a storage for 300 days might even be required. In such districts, however, surface water is very rarely used for town supplies. There are few suitable collecting areas, and the rainfall is too low and too varied in its seasonal distribution to justify any attempt to obtain water from such sources. In those parts of England in which surface water can be rendered available a drought extending over 120 days, or a succession of droughts corresponding to that period, must be so rare as to be phenomenal. In works of such vast importance all errors must be on the safe side; it is wisest, therefore, to make provision for 150 days' drought even in districts with heavy rainfalls, and in less favoured districts to provide for the storage of 200 days' supply. This appears to be the general opinion of the most eminent engineers It is impossible to give any precise rules as to the relation of the rainfall to the amount of storage. Mr. Hawksley's well-known formula gives results which confirm the opinion expressed by Dr. Pole, quoted below. Let D = the number of days' storage necessary, and F = the mean annual rainfall of a long series of years, then according to Hawksley

$$D = 1{,}000 \div \sqrt{F}.$$

With a rainfall of 25 inches this formula gives 200 as the number of days' storage required; with 49 inches 143 days would suffice. Dr. Pole says "the general judgment of

experienced practitioners appears to be that for large rainfalls a storage of 150 days or even less will suffice, but in drier districts it may be necessary to go as high as 200 days; . . . and this is a provision which may reasonably be borne." The extent to which the character of rain water can be affected by the surfaces from which it is collected was referred to in Chapter III.

Subsoil water is not utilised nearly to the same extent for supplying towns as surface and river water, whilst rural communities still continue to be supplied chiefly from this source. The factors upon which the amount of water available in the subsoil can be estimated have already been considered. A single well may yield sufficient water for a large village, or if the subsoil be chalk or sandstone and admit of headings being driven in various directions from the bottom of the well, one well may even supply a town of moderate size. Where, however, two or more wells are required, necessitating a corresponding number of pumping stations, a considerably increased expenditure is incurred. A village may sometimes be supplied from a single well in a patch of gravel, but usually such drifts are not sufficiently extensive or thick to yield a constant supply of any magnitude.

The chalk formation in most cases contains a large store of excellent water, but a single well, even with headings, rarely yields enough water for a large town. The drainage area of chalk wells cannot be estimated, since the water exists chiefly in and travels through the fissures, and but very slightly, if at all, through the chalk itself. It is evident therefore that the freedom with which water percolates through a chalk subsoil will depend upon the abundance and size of these fissures. If the fissures are numerous and large the drainage area may be very considerable. The well referred to on page 324 as being affected by the sea, 1½ miles away, is sunk in the chalk. Cases are also recorded in which impurities have

been found to enter a well after travelling a very considerable distance through such fissures. As an example of the amount of water obtainable from wells in the chalk, the case of Croydon may be cited. The old waterworks are close to the town, and comprise four wells sunk in the chalk within a space of 100 feet square. The level of the water in the wells is not more than 25 feet from the surface, and the fissures yielding the chief portion of the supply are about 25 feet lower. Over 3,000,000 gallons per day have been pumped from them. To meet the increasing demands of the town a new well was opened in 1888. This is sunk 200 feet, all in the chalk, and is 10 feet in diameter. Water was first found at 87 feet. At 142 feet from the surface and below headings have been driven. The yield from the well was 130,000 gallons a day, but the first fissure cut by a heading increased the daily yield to 600,000 gallons, and when the yield reached 2,500,000 gallons a day the work in the well had to cease through the inability of the two 24-inch pumps to keep the water down. The total length of the headings is 813 yards, and they are generally 6 feet high and 4½ feet wide. The storage capacity of these and the lower part of the well is about half a million gallons (*Borough Engineer's Report*, 1890). A well such as that just described is usually spoken of as a "deep" well, although sunk entirely in one pervious stratum. The chalk, new red sandstone, oolite, and greensand contain vast stores of water of excellent quality accessible over very large areas to the well-sinker or borer, but it must not be forgotten that there is a little uncertainty in searching for water at such depths. The most experienced geologists are sometimes at fault. The variations in thickness of the water-bearing stratum and of the strata resting upon it, the possibility of hitherto unsuspected faults existing, must all be borne in mind. The water, also, when found, may be quite unsuitable for domestic purposes. Thus in Essex many of the borings

piercing the London clay yield a water containing so much sulphate of magnesia as to be aperient in property, whilst others have yielded a water so brackish as to be useless. The presence of beds of gypsum and of rock salt in the new red sandstone must not be forgotten, the former rendering the water excessively hard and the latter salty. At Rugby a well sunk 1,200 feet yielded only brackish water, and at Middlesborough a well which was sunk for obtaining a pure water yielded so strong a brine that salt is extracted from it. At Wickham Bishops, Essex, a boring was sunk to a depth of about 1,000 feet without water being found, yet everything had indicated that an abundance of water would be reached at a depth of about 500 feet. The section showed that there existed a previously unknown and unsuspected fault crumpling the London clay back upon itself, so that this stratum had to be twice pierced. When the second layer had been penetrated and no water discovered the work was abandoned. In other places the fall in the water-level from the heavy continued pumping indicates that a time may come when such supplies will fail, and unless the site of the well has been carefully chosen, others may be sunk in such positions as seriously to affect the supply.

The amount of water obtainable from a deep well in any particular locality is difficult to predict, but a consideration of the conditions bearing thereupon, referred to in Chapter VI., will assist us in arriving at fairly safe conclusions. The information contained in the next chapter, gathered from experienced well-sinkers, engineers, geologists, and others, showing the actual amounts of water which have been obtained from various underground sources during recent years, will also be a useful guide.

I cannot do better than close this chapter with a quotation from an address by Mr. W. Whitaker, F.R.S., recently delivered at the anniversary meeting of the Geological Society. He says: "Underground water is

indeed a very complicated and difficult subject, making strong calls on our reasoning powers. In the case of springs and streams we are dealing with facts, things that anyone can see; but in the case of underground water it is a very different matter; we have to make inferences, and though our inferences may be warranted by all that is known on the subject, yet it is seldom that we can speak with certainty. There is, therefore, a certain charm in questions as to underground water that is wanting in the more prosaic subject of surface-waters.

"The source must be some permeable formation of good thickness and with a broad outcrop, as the quantity of water in any permeable bed must depend on the amount of rain that falls upon it, and this latter greatly on the area of surface exposed. A well, therefore, must either be upon the formation that is to be the source of supply or upon some overlying formation through which it can be carried to the water-bearing stratum. These two classes of wells sometimes differ greatly.

"In the first case, the well should be at a part towards which underground water flows: away, therefore, from an escarpment or ending-off of a formation, and towards the line of outcrop or where the next overlying formation comes on. It should also be in low ground, as a rule, so as to avoid needless depth. In the second case, when a well has to be taken through some thickness of overlying beds to reach the water-bearing bed, different conditions sometimes arise, unless the well is near the outcrop of the water-bearing formation.

"The method of flow of water through the rocks must also be considered. In some, this is mostly through the pores or the spaces between the particles of which the rock is built up; but in some water-bearing rocks very little passes in this way. Sometimes the planes of bedding afford a sort of channel, but at others these are closed and well packed together. Often the flow is along joints, or

structural planes that have been formed after consolidation: fault-planes may act in a like way.

"Though, of course, every opportunity of studying the rocks at the surface should be taken, it must not be expected that they will show the same features when found at great depths, beneath a thick mass of overlying beds. Often it is ascertained that beds which are fairly open in sections that can be seen have their fissures, etc., more or less closed up below ground: for instance, at Richmond, where the Chalk has been worked horizontally under a great depth of Tertiary beds (from a little under to a little over 300 feet), a very great length of gallery has been driven with the result of cutting comparatively few fissures, and none of those large, so that but little water has been got; while in the waterworks for Southampton, placed on the Chalk close to its outcrop, so that there was no occasion to sink to a great depth, a very much less amount of gallery has yielded a very much larger quantity of water.

"Moreover, the Kent Company, which gives our largest supply solely from wells, has done comparatively little in the way of driving galleries, but has depended largely on simple wells and borings, which are either on bare Chalk or where there is no great thickness of other beds above the Chalk.

"Again, the underground condition of a rock may vary greatly in places near together. The Brighton Waterworks give a good example of this; for, while at the Lewes Road Station the fissures in the Chalk are many and small, in the Goldstone Bottom Station, not far to the west, the fissures are mostly large, but few. Yet the two stations are at about the same horizon in the Chalk, and there is no apparent reason for this difference between them. A somewhat similar case is that of Croydon, where the old works in the town give a much larger supply, without galleries (or at least with merely short connexions between

the wells), than that which is got from the new works, but little lower in the Chalk, at Addington, where there is a great length of gallery.

"These are cited as illustrations of the uncertainty of underground work, an uncertainty with which many of my engineering and some of my geological friends are fairly familiar; and they should prepare us to be somewhat cautious in predicting, at all events before we know.

"Not only do we find that beds pierced at great depths often have a character different from that which they put on at their outcrop, but also that waters found at great depths often vary much in their mineral contents from those in the same beds much nearer the surface. A well-known case of this sort is that of the waters in the Chalk under London, where the Chalk is thickly covered by Tertiary beds, those waters differing greatly from the waters in the bare Chalk northward and southward, in the increase of alkaline salts and the decrease of lime-salts.

"Other like cases have been described in waters from Jurassic beds, as at Swindon and at Woodhall Spa, in both of which a large amount of common salt occurs, while in the latter case there is a regular mineral water. It is found, too, that waters in wells from the sandy beds of the Wealden Series often contain a goodly proportion of carbonate of soda.

"Such matters, and the occurrence of mineral waters generally, point to the need of alliance with chemists, and the advantage of getting full analyses of well-waters, which show the mineral contents and do not merely refer to organic purity or impurity. With this help we may be able not only to trace the origin and history of a water, but may also some day learn something of those slow, quiet, unseen changes that go on underground, through the agency of water in the rocks: a subject of which, I think, we know little as yet, at all events in this country."

It is advisable in all cases to derive the whole supply

required from one and the same source. In many towns, especially on the Continent, water is derived from a number of different sources. This may have been due to the original supply proving inadequate on account of the increase in population and the increased consumption of water required by a higher standard of cleanliness. In Paris a dual system of supply has been adopted. The one furnishes unfiltered river water, and is used for municipal purposes and for supplying baths, fountains, etc. The other furnishes a purer water, derived chiefly from springs in the valley of the Vannes. The suggestion to adopt such a dual system elsewhere has not been favourably received. Apart from the enormous additional expense necessitated by a duplicate system of mains, it has many other objectionable features. At Berlin the water of the Spree, after filtration, supplies a portion of the inhabitants, whilst others are supplied from the Tegeler Lake. Vienna derives water from springs in the Styrian Alps and from wells sunk in the subsoil on the banks of the Schwarza. The water supply to Brussels is most unsatisfactory, and is derived from the subsoil, from the Harre, and from the drainage of the Forests of Soignes and Cambre. The Leipzic waterworks present several peculiarities. Water from the Pleisse is run into reservoirs, and the water filters through the natural gravel bottom, and is collected in earthenware pipes, with open joints, which are laid in the subsoil for this purpose. This supply is supplemented by the yield from five groups of Artesian wells. The water supplying Stockholm is derived in part from a lake and in part from the subsoil, almost exclusively from the latter during the winter months. Interesting details of these and other works are given by Palmberg and Newsholme in their *Treatise on Public Health and its Applications in different European Countries.*

CHAPTER XVIII.

THE PROTECTION OF UNDERGROUND WATER SUPPLIES.

NOTWITHSTANDING the immense progress which has been made in this country in recent years in practical sanitation and in sanitary administration, outbreaks of preventable disease due to the pollution of water-supplies have been all too frequent. Common sense suggests that if it is desired to obtain a pure supply of water, a source should be selected, removed as far as possible from any contaminating agencies, and that every reasonable precaution which science or experience can suggest should be taken to prevent either wilful or accidental pollution. At present only underground sources are being considered, waters derived from streams and rivers being discussed later. Both, of course, are derived from the same source—the rainfall—but the modes by which they may become polluted are somewhat different, and the precautions which require to be taken to prevent pollution are also different. Whilst streams are fed in a great measure by the rainfall which has not penetrated the ground, but merely run over the surface, the subsoil water and the water in the deeper pervious strata is derived entirely from the rainfall which has been absorbed by the soil, and which has percolated to the depth at which it is found. It is obvious, therefore, that the collecting areas in the two cases must be very different in character. The one requires an impervious or but slightly pervious strata, the other a pervious surface. The pervious surface will almost certainly, in this country

at least, be tilled for agriculture, and more or less highly manured. Such manurial matters as are soluble will be dissolved by the rainfall, and the finer particulate matter will become suspended in the water. All underground waters, therefore, are more or less liable to pollution at what may be regarded as their source, the rain which has fallen upon the pervious ground, and if they did not afterwards undergo some efficient process of purification, underground sources would have to be abandoned. In shallow wells constructed near houses the water is frequently very impure, and is notoriously liable to specific pollution, a large proportion of the outbreaks of typhoid fever recorded in this country being due to the use of shallow well water. Too great proximity to houses and sewers can be avoided, but that no house drainage or human excreta shall be placed upon the gathering ground is a matter beyond control. Circumstances, therefore, compel the use of water liable to specific pollution, and the point for consideration therefore is, Can this water undergo naturally such a process of filtration as will render it for all practical purposes absolutely safe for domestic use?

The word "filtration" rather than purification is here used intentionally, because the specific material which has to be removed from the water is not something in solution, but particulate matter in suspension, and as has been already remarked this particulate matter, though of extremely minute dimensions, is capable of being removed by filtration. This particulate matter also must be living, and there is every reason to believe that neither the typhoid nor the cholera organism can survive more than a limited time in water, especially if the water be free from polluting matter, and that they will not live long in unpolluted soil. If therefore the subsoil can so filter the water passing through it as to remove these living organisms, or if these organisms in traversing the subsoil find themselves in such an unfavourable environment that

life is impossible, it is obvious that water which has percolated through a sufficient depth or flowed longitudinally through a sufficient thickness of the subsoil, will contain none of the specific organisms, and can be used without risk of producing these specific diseases. The water which falls upon the surface of a porous soil tends in a downward direction until it reaches the level of the subsoil water. It then takes on a lateral direction, flowing through the interstices in the stratum towards its natural outlet, whether this be a well-defined spring, a flowing stream or the ocean. During its progress the organic impurities at first absorbed are more or less completely removed. The organic matter in solution becomes oxidised or "burnt" up, and we find the ashes, carbonates, nitrates, sulphates and phosphates only in the water if the oxidation has been complete. The living organisms are more or less completely removed, in part by the natural filtration and in part probably by other agencies which cause their destruction. A water originally very impure, and specifically polluted, may become hygienically pure and wholesome by passing through a sufficient thickness of subsoil. The upper portions of the soil, to which air has comparatively free access, especially if covered with vegetation, have the most powerful action. Nitrifying organisms abound, and convert the dead organic matter into simpler inorganic compounds, and the living organisms are more or less completely filtered out. So complete may be this purification that from properly constructed deep wells water may often be obtained almost, if not absolutely, free from organic matter, living or dead. These natural purifying processes have not as yet been sufficiently studied, but sufficient is known to enable fairly safe conclusions to be drawn as to the means which must be adopted to obtain a pure water supply from underground sources.

Before referring more fully to these natural processes of purification, the brief consideration of the sources of

underground water supplies known to have caused outbreaks of typhoid fever or cholera will prove instructive. The late Dr. Ernest Hart prepared a historic summary of local outbreaks of typhoid fever in Great Britain and Ireland, occurring between 1858-1893, due to specifically polluted water, which summary contains a tabulated analysis of 205 epidemics. Considering only those due to the use of subsoil water—and these form about two-thirds of the whole—it will be found that nearly all were due to the use of water derived from shallow wells situated within a very few feet of defective cesspits, leaky cesspools or sewers. Take two examples selected at random from the more recent outbreaks. "Well sunk in gravel with strong clay watertight bottom. Drain ran close to the well used by the first patient and leaked into the well. Evacuations thrown into the common ashpit and adjacent sink. All wells in the locality open to the same water movement and sunk in soil charged to overflowing with impurities of every kind." Or again, referring to a much more serious epidemic, "Water supply obtained from three wells with three headings, two headings serving as connecting tunnels between the three wells. The heading driven from one well only in the early part of the year, a large fissure struck, the inrush of water being so great that the men in the tunnel had to fly for their lives. Soil overlying the chalk in which were sunk these wells liable to sustained pollution by sewage." With each outbreak the same story is related. Wells sunk in a sewage-polluted subsoil, near drains, sewers, or cesspools, or in a fissured stratum, the fissures of which communicated more or less directly with the source of pollution. In no instance is there a record of an outbreak being produced by water derived from a well sunk in a carefully selected site, and in which the simplest precautions had been taken to prevent pollution. The wells were so situated that anyone possessing a smattering of knowledge of sanitary matters would have

said that sooner or later they would become specifically infected and an outbreak of disease result. If the various reports upon outbreaks of cholera are consulted the same conditions are found, the absence of all precautions, and the source of fæcal contamination easily traceable. The evidence gained from dearly bought experience is in each series of cases the same.

Professor Pettenkofer has long taught that a polluted soil is the best nidus for the propagation of the typhoid bacillus, and Dr. Hauser, of Madrid, expresses similar views with reference to the cholera bacillus. That the soil is the natural nidus of these disease-producing organisms outside the human body is now generally conceded, but there are soils and soils, and to explain all the facts it is necessary to assume that only certain soils are favourable, and that in others the conditions are so unfavourable that multiplication therein is impossible. The favourable soils appear to be those which contain organic matter, especially of animal origin, sewage and excremental matters generally The unfavourable soils are those which contain least organic matter, and more especially are free from sewage pollution. These, of course, are not the only factors, but they are the only ones bearing directly upon the subject under consideration.

In an investigation made on behalf of the Local Government Board, a preliminary report of which has recently been published, Dr. Sidney Martin found that the typhoid bacillus and the colon bacillus (an organism allied to the typhoid bacillus, and found in large numbers in all sewage matters) rapidly increased in the sewage-sodden soil from Chichester, whereas in virgin soil under similar conditions they very speedily died out. When black mould containing organic matter was used, both bacilli retained their vitality for a considerable period, whereas in none of the experiments with virgin soil did any growth whatever occur. Still more recently Dr. Robertson has published the results

of a series of experiments conducted at St. Helens, of which town he was the Medical Officer of Health. The results were very suggestive, and proved that the typhoid bacillus was capable of multiplying rapidly under certain conditions. He inoculated a large quantity of broth with the typhoid bacillus, and with this infected various patches of ground. Upon the patches which were manured with dilute organic solutions the typhoid bacillus throve lustily, upon the patches not so treated they languished and died. A very significant fact is also recorded by Dr. Robertson. When the ground was infected 18 inches beneath the surface the bacilli grew to the surface; when the surface was inoculated they only grew downwards to a depth of 3 inches. This inability of the rainfall to carry the organisms deeper into the soil, and the fact of the deep cultures growing upwards to the surface confirm the view that it is only in the surface soil that any active propagation can take place. At a little depth below the surface the conditions become so unfavourable that any growth which may take place is in an upward direction; at a greater depth probably no growth whatever would occur, and the organisms would quickly die.

Abba, Orlandi, and Rondelli * have recently conducted certain investigations at Turin to test the filtering power of the subsoil from which the water supply to the city is obtained. For this purpose they used diluted broth cultures of *Bacillus prodigiosus*. They found that this bacillus penetrated to a depth of 3 metres (about 10 feet) but did not pass into the ground water save after heavy and persistent rains.

Whatever may be the explanation, there is much evidence to prove that at a very limited depth beneath the surface of a compact porous soil the subsoil and the subsoil water are practically sterile. Koch appears to attribute this to

* *Zeitschrift für Hygiene*, vol. xxxi., 1899, p. 66. Abstracted by Dr. McWeeney in *Journal of State Medicine*, vol. viii., p. 47.

a mere process of natural filtration, since in his paper on "Water Filtration and Cholera," he says, "Rain water when it sinks into the ground and ultimately becomes subsoil water passes through far thicker layers and with far less rapidity than river water when passing by artificial filtration through sand filters. If the sand is only sufficiently granulated we have in soil filtration a much more perfect process than is at our disposal in artificial filtration. This is confirmed by the investigations of C. Fraenkel, who has shown that subsoil water, even in a soil which has been much and for a long period contaminated, as in the case of Berlin, is quite free from germs. In other places the same results have followed from investigations made on this point." Quite recently I have confirmed these observations in some experiments made with sand taken from various depths beneath the surface. Up to a depth of about 4 feet organisms were present, but at 4 feet they appeared to be anaerobic, below 5 feet I could not find any organisms whatever.

The bacterial purity of subsoil water, however, is not altogether due to the efficiency of the natural process of filtration. No doubt the conditions which obtain underground are very unfavourable to the growth of many organisms, and there is abundance of evidence to prove that the bacteria producing typhoid fever and cholera are in a more or less unfavourable environment when in water, and can only survive for a very limited period. Most of the experiments recorded, having reference to the vitality of the typhoid bacillus in water, have little or no bearing upon the subject under consideration, the conditions under which they were conducted being so different from those which obtain in nature. Others again are unreliable on account of fallacies underlying the methods of examination adopted. This question of survival is a point of the utmost importance. Again, as far as is known, typhoid fever and cholera are exclusively human affections, and

there is no evidence to prove, nor are there any recorded facts which necessitate the assumption, that cattle of any kind suffer from these specific diseases and discharge excremental matter capable of specifically infecting the soil.

The remarks already made with reference to soil pollution apply equally to those cases in which the source of pollution is beneath the surface, as to those in which the filth is deposited upon the surface. Fortunately all sewage contains microbes which, during their growth and development, tend to break down the dead organic matter upon which they subsist, into simpler and more stable forms, that is to say, under suitable conditions sewage will purify itself. This fact, which is only just beginning to be recognised, is being taken advantage of for the purification of sewage, in the so-called bacterial filters of Dibdin, Ducat and others. Everyone who has had to watch the process of excavation in the vicinity of defective sewers and cesspools has observed that there is little or no evidence of pollution in the subsoil, except in the immediate vicinity of the defects which permitted the pollution. This purifying action of the subsoil is easily demonstrated on any fairly large patch of drift upon which a village stands. On the side furthest from the natural outlet of the water, the wells yield what may be called the normal water of the patch, containing very little organic matter and only comparatively small quantities of chlorides and nitrates. Within the village many of the wells will be found to be highly polluted, but almost invariably some will be found which, either on account of their better construction or their greater distance from a source of pollution, are also practically free from organic matter, though containing large quantities of chlorides and nitrates. On the side nearest the natural water outlet the same condition is found, the only evidence of the previous pollution being the ashes of the consumed organic matter. Besides the chemical change the natural process of filtration has taken

place. Subsoil water travels horizontally at a very slow rate indeed, compared with the rate at which water is passed through artificial filter-beds, and it is practically impossible for particulate matter, living or dead, to be carried any distance by the current.

In certain places, however, the subsoil water may flow with an appreciable velocity, and in channels more or less defined. The reason for this can easily be understood. Suppose that a valley scooped out of some impervious stratum, such as the London clay, were to become obliterated by being filled with sand and gravel. A portion of the rainfall upon the now exposed area would percolate into the sand and tend towards the centre of the original valley, finally making its way to the lowest point. The greatest flow would be along the bottom of the valley, and doubtless here in the course of time, it might be ages, the resistance would diminish from the washing away of the finer particles, and after reaching this channel, possibly no further purification or filtration would take place. Herein lies one of the dangers of the use of subsoil springs. These springs are but the natural outlet of the subsoil water, and impurities entering the subsoil immediately over the line of flow are much more likely to be dangerous than impurities entering elsewhere. The nearer the spring or the line of flow the greater the danger and the greater the need for protection. In the neighbourhood of rivers also, there is often a considerable flow of water in the subsoil, rendering it necessary to direct particular attention to the protection of the ground above the point at which water is being abstracted.

So far it has been taken for granted that a subsoil of uniformly compact consistence was being considered, such as deposits of drift, beds of sandstone, etc.; but there are other pervious water-bearing strata, of which chalk is the best example, which are not uniform, but full of fissures. It is obvious that water which has once entered these open

fissures will undergo little further chemical filtration, and that polluting matters may be carried great distances therein. Here again, however, the upper surface of such a stratum is almost certain to be fairly compact, the fissures being obliterated by the surface soil, and water passing through will be more or less completely purified. In travelling along the open fissures, the velocity of flow (save in the immediate vicinity of the natural or artificial outlet) must be very slow, giving time for sedimentary matters to be deposited, and for such organisms as the typhoid and cholera bacilli to die and be carried down therewith. Water collected from deep wells in fissured strata, at points many miles removed from the exposed collecting area, is usually found to be particularly free from organic matter, and to contain few if any bacteria; but the freedom with which water can traverse these fissures has too often been painfully obvious in counties near the coast, inasmuch as wells—sunk at great cost—have had to be abandoned on account of the rapid infiltration of sea water. By continuous pumping, the water level had been so depressed that a return current from the sea was set up. The area which may be directly drained by a well in a fissured stratum is therefore enormously larger than that which can be affected in a uniform porous stratum.

To ensure a continuous supply of hygienically pure water from an underground source, many points have to be taken into consideration; and no general rules can be laid down applicable to all circumstances. There are many wells used for large public supplies which ought to be abandoned, on account of their proximity to groups of dwelling houses. In many cases these houses have been erected since the works were established; too small an area of land was acquired in the first instance, and the mistake cannot now be rectified. There should be an area of ground around each such well under the absolute control of the purveyors of the water. The well should be con-

structed so as to admit water only at the lowest point possible. If the pumping machinery is in or over the well care should be taken to prevent dirt of any kind, especially from the workmen's boots, reaching the water. The immediate vicinity of the well should either be uncultivated or laid down to grass, but not fed. An outer ring should be similarly laid down, but cattle might be permitted to feed thereon. These two rings may be called the inner and outer protective areas, and the inner ring should be so enclosed that no one can enter "except on business." The area of this inner ring should be, at least, as large as the area of the cone of depression produced by the pumping. For example, suppose that 45,000 gallons are being pumped per day from a sandy subsoil, and that the depression of the water level in the well caused by the pumping is 9 feet. Each cubic foot of the saturated sand would yield about 1½ gallons of water. To yield the 45,000 gallons therefore, 30,000 cubic feet of the subsoil would be drained. The cone of depression having a depth of 9 feet, the area of its base would be 10,000 square feet, representing a circle with a radius of 57 feet, the well being at the centre. The cone, however, has not straight sides, and to be perfectly safe therefore a radius of 30 yards had better be allowed. The outer protective area should have a radius double or treble that of the inner area.

In a uniform subsoil the rapidity with which the water travels toward the well decreases as the square of the distance. If within 3 feet of the well the movement of the water is at the rate of 1 foot per second, at 30 feet the movement of the water will only be at one one-hundredth of that, or 1 foot in 100 seconds, and at 30 yards the rate will be 1 foot in 900 seconds. Therefore, at a certain distance away from the well the movement of the water is so slow that perfect filtration is secured. That is to say, the water passes through the subsoil very much more slowly than it passes through the sand in an ordinarily

constructed filter, and for that reason the protective area need not extend, assuming my views to be correct, more than a limited distance round the well.

I am strongly of opinion that this protective area should in future always be insisted upon, but its extent may have to be defined in each individual case. The conditions vary so greatly that no general rule can be adopted. In deciding, many factors have to be taken into account: the contour of the ground, the depth and nature of the subsoil, the height of the subsoil water and the range of its fluctuations, the possible sources of pollution, the amount of water to be abstracted, etc. The direction of the flow of the subsoil water must also be considered, since polluting matter entering the soil on the side upon which the water is flowing towards the well is naturally more dangerous than if it enters on the side where the flow is from the well. Naturally also a much larger protective area will be required where the subsoil water is only a few feet from the surface, than where it is 15 to 20 or more feet below. Where the underground water is known to be flowing in a fairly well defined underground channel, the protective areas had better be elliptical, the longer axis having the direction of flow, the well being on this axis but nearer the end towards which the water is flowing. This elliptical protective area will in most cases be desirable for springs, for reasons which are so obvious as not to require enumeration.

In many instances the protection of the water is rendered more difficult, and the problem becomes more complex, from adits or collecting channels being driven or trenched in one or more directions in order to increase the available supply of water. These drains should be laid as low as possible. Only under exceptional circumstances should they be less than 10 feet deep, and the trenches should be very carefully filled in and tightly rammed. The whole

of this trenching should be well within the inner protective area.

Where the subsoil is fissured the danger of pollution is greater and protection more difficult, since the source of the danger may be concealed and may almost defy detection. A striking example of these dangers was furnished by the outbreak of typhoid fever at New Herrington, Durham. Any fissure so directly connected with a well would probably give indications of its existence soon after heavy rains by the effect upon the water in the well, by rendering it more or less turbid. In all cases where such turbidity is produced, however slight, there is cause for anxiety, and both the well and its surroundings should be examined to ascertain the cause. If a heavy rainfall can wash into the well visible particles it could still more easily carry with it the minute organisms which cause disease, should such unfortunately happen to be within its sphere of influence. Surrounding such wells there should be protective areas, but their form and dimensions could only be defined after a careful survey of the district, more especially with reference to the dip of the stratum, and the general direction of the fissures. The locality where any fissures were suspected of reaching near the surface would require an especially careful examination. If within the well or adits there were numbers of fissures yielding water some useful information might possibly be obtained by an examination, chemical or chemical and bacteriological, of the water from those flowing most freely. Such wells require careful watching, and frequent systematic analyses should be made to ascertain to what extent, if any, the quality of the water is affected by the rainfall. The greater the variation the greater the risk, especially if the variations rapidly follow the rainfall and are accompanied by an equally rapid variation in the flow. If the variations in character and quantity are but slight, and only occur some time after the rainfall, and especially

if there is never any indication of turbidity, then the risk is a minimum and may possibly be ignored.

Deep wells drawing water from subterranean sources overlaid by thick beds of impermeable clay are generally considered to yield the purest and safest of waters. Doubtless where the site has been judiciously selected and the well carefully constructed, such is the case, but deep wells as well as shallow wells may be defective in construction and admit of pollution taking place. Wherever constructed the gathering ground feeding it must be some distance away. This outcrop should be examined, the more carefully the nearer it is to the well. It is desirable to know if any possible sources of danger exist, even if they cannot be removed, especially if within one or two miles of the well. At a further distance, possibly they may be neglected as powerless for harm, the time which would elapse between the rainfall reaching the ground surface and the well being ample to secure a satisfactory purification. The chief source of danger is from the admission of possibly polluted subsoil waters. It is often difficult to effectually block out the water from superficial strata, but it can be done, and should be done. For further security there should be a small protective zone kept free from all pollution. Greater care also should be taken within the well to prevent dirt, especially from the shoes, defiling the staging and being washed into the well. Samples of the water collected on a uniform plan, and at regular intervals, should be submitted to analysis and careful records kept. For this, however, to be of real service the water must be derived entirely from the deep source. If there is a variable admixture with subsoil water, the value of the analytical record is greatly decreased. Such careful and systematic analysis will detect any variations in the character of the water, and possibly sound a note of warning on the approach of danger.

Where bored tube wells are used and the tube forms the

suction pipe of the pump, danger of insuction of subsoil water, possibly contaminated, certainly exists and should be carefully guarded against. The action of the pump is to withdraw the atmospheric pressure from within the tube, and the excess of pressure outside will force air or water through the most minute defect, through apertures so minute that under ordinary circumstances neither would have passed. When this action has once been set up, the openings are bound to increase in calibre and insuction becomes still more easy.

Whilst the deep wells constructed to supply large communities are usually carefully made, sufficient care does not always appear to be taken in the construction of deep wells when only intended to supply a farm or a few cottages I have known several hundreds of pounds spent in boring and sinking such a well, and then, to save a few additional pounds, the sunk portion has been so defective and the top so badly protected that the water has become polluted.

Whether underground water be drawn from a superficial or deep water-bearing stratum, there is no doubt that the chief factor in protecting it from pollution is the provision of an area round the well or point of collection which is under the control of the owners of the well, and which is kept free from all matters of an objectionable character. In the past too little care has been taken, but it is tolerably certain that in future both Parliament and the Local Government Board will insist upon efficient protection, and the provision of ample protective areas. Existing sources of supply should be examined and steps taken to secure the necessary protection when this is defective. If such is not possible—and in some instances this will probably be found to be the case—efforts should be directed towards providing a less dangerous source of supply. It will be better to voluntarily abandon the works now than to wait until an outbreak of typhoid fever or cholera arouses public indignation and compels their abandonment.

Finally, all public supplies should be periodically examined even to the minutest detail and the results recorded. These inspections should be supplemented by chemical or chemical and bacteriological analyses at more frequent and regular intervals. Were the precautions above indicated universally adopted, I am convinced that there would no longer be any fear of the specific pollution of our underground water supplies, and that one of the most frequent causes of the epidemic prevalence of cholera and typhoid fever would cease to exist.

CHAPTER XIX.

THE PROTECTION OF SURFACE-WATER SUPPLIES.

Much more attention has been given in recent years to the protection from pollution of river, spring, and well water, than to the protection of surface-water sources of supply. This is doubtless due to the fact that all the recent large outbreaks of typhoid fever have been due to the use of river or spring water, and the smaller outbreaks to polluted shallow wells.

Reference to the Local Government Board and other reports on outbreaks of typhoid fever shew that surface-water collected on a large scale for the supply of a town or series of towns or villages has rarely been charged with the spread of that disease. This is a subject of congratulation to those towns, so numerous in the north of England, deriving their water from such sources. I attribute this immunity entirely to one cause, the storage of the water in large reservoirs. The storage usually amounts to from 100 to 200 days' supply. During this storage the water is fully exposed to the air for oxidation, and to sunlight for insolation, and the long period of rest secures more or less thorough sedimentation. I feel tolerably certain that the typhoid organisms, if introduced into such a reservoir, have but a remote chance of surviving and reaching the water mains in a living condition. The environment is distinctly unfavourable; the sunshine quickly kills them as they approach the surface, and by sedimentation they are deposited with the mud at the bottom of the reservoir.

We cannot be certain, however, that special conditions may not arise permitting such organisms to reach the mains; hence, apart from sentiment, no reasonable effort should be spared to prevent the pollution of the water by any matter which could possibly be infected. To secure at all times a thoroughly wholesome, bright, and palatable water should be the aim of every authority having control of any public water supply.

Where full control of the collecting area is secured and the whole converted into prairie land without houses or farms, mines or other works upon it, and with but few public thoroughfares, and the storage reservoir is of very large size, filtration may possibly be dispensed with, but although it ceases to be a very important factor, I should always regard it as highly desirable.

To obtain full control of a gathering ground is, however, a very difficult and often impossible procedure. The subject was thoroughly discussed recently before a Parliamentary Committee when a Bill was being considered in which a water authority sought to obtain this complete control. Partial control had already been obtained and many houses demolished. Certain farms had been acquired and laid down entirely to grass. There were many footpaths, certain highways, stone quarries, etc., and the evidence showed that so many interests were involved, public and private, that absolute control was impossible. People walking along these footpaths and roads in secluded districts cannot be prevented from obeying the calls of Nature. Accommodation may be provided at quarries, but no one can compel the men to use them and them only. Hence when all has been done there are risks which must be run and against which some other mode of protection must be devised. In this country, which is becoming more and more thickly populated, and where even the most remote districts have charms for tourists, I doubt very much whether any upland surface can be kept absolutely free from pollution.

Ample storage may possibly be in many cases a sufficient safeguard but, as we shall see shortly, there are other reasons for preferring filtration also.

There are many gathering grounds, however, where such efficient protection is impossible, and where a certain amount of pollution by manurial or sewage matter is unavoidable. These are districts in which more or less of the land is under cultivation. The land may be so valuable that purchase is out of the question, or there may be other insurmountable difficulties with reference to its acquisition.

Even in these cases very often great improvements may be effected by efficient supervision of the sanitary arrangements, scavenging, etc., by constructing drains and sewers to convey the polluting matter beyond the boundary of the watershed, by arranging that no manure containing human excrement shall be used. Where such arrangements cannot be made the question must arise as to whether the watershed should not be abandoned or whether the storage with filtration can be depended upon for preventing any infective matter reaching the mains. Every case of this kind must be discussed on its merits, and after a thorough and systematic examination of the watershed. I have seen reservoirs inefficiently protected and with footpaths along the banks. On these footpaths I have seen human excrement, and in the water I have seen drowned animals. It is obvious, therefore, that so far as is possible both animals and human beings should be prevented from gaining access to the reservoirs. Sometimes the water from such an unsatisfactory collecting area can be utilised as compensation water for manufacturing purposes.

Where surface-water supplies are used a large storage is always necessary, in order to impound water during the wet seasons for use during the dry. This alone assures storage sufficient for hygienic purposes, for bleaching, more or less completely, peaty waters, for allowing sedimentation, and time for the destruction of the typhoid microbe. The

greater the storage, the better for all these purposes. As previously stated, such storage is probably sufficient, save under very exceptional circumstances, to insure safety. If the water gets very low, however, in the early autumn, and very heavy rains come on suddenly, it is quite possible for impure water to reach the mains. After a long dry season, polluting matter, if any, would accumulate on the watershed and be washed down with the first storm. The water then would be unusually polluted, and it would have unusual facilities for rapidly traversing the storage reservoirs, and reaching the consumers. Efficient filtration would now be the last and only line of defence.

Filtration, efficiently conducted, would at such times prevent 99 per cent. of the organisms from entering the mains, and experience teaches that the risk of using such a water, properly filtered, is very small indeed. But apart from protection from infection filtration is almost indispensable, if we wish at all times to supply a bright and palatable water. We cannot prevent low forms of vegetable and animal life being carried into the reservoirs, nor can we prevent their multiplication therein. If the water is not filtered, these are delivered with the water to the consumers, and impart to the water an unsightly appearance, and sometimes a very disagreeable odour. Even when not visible at the time of delivery, they may so rapidly multiply afterwards, that vessels in which the water has stood for a night or two become coated with a more or less slimy deposit, or with a distinct green growth. This condition is one which frequently causes loud complaints, and such a water cannot be regarded as sufficiently satisfactory for a public supply.

To sum up, I strongly advocate three distinct lines of defence:

1. The utmost possible control of the watershed or collecting area.
2. Very ample storage.
3. Sand filtration.

Where the water is acid, or has a plumbo-solvent action, the filtration should be through a mixture of sand and limestone, and the softer the limestone the better, the object being to neutralise the acid and cause the water to dissolve a small quantity of carbonate of lime, as by this means the plumbo-solvent action is more or less completely destroyed.

The Local Government Board has recently issued a circular bearing upon the protection of water supplies, and suggests that every sanitary authority should obtain accurate information in such matters as the following:—

1. *Where water is derived from gathering-grounds or from springs.* Whether drainage from human habitations, farm-yards, and the like finds its way directly or indirectly into the reservoir or to any part of the water service, and whether risk of access to the water of human excreta and similar refuse is likely to arise.

2. *Where water is derived from deep wells.* Whether surface or other water liable to be contaminated by drains, sewers, cesspools, and the like reaches, or is liable to reach, the wells. The existence and direction of fissures in the strata deserve especial consideration in this respect.

3. *Where water is derived from shallow wells.* Whether the wells are so circumstanced that they run risk of contamination by reason of drains, privies, cesspools, or middens, or by the deposit of manure—whether derived from human excreta or not—in or on the ground in the neighbourhood of the wells.

The district councils are reminded that they are responsible for the wholesomeness of water which they themselves supply, and that they should by careful inquiry make themselves acquainted with the sources, nature, and quality of the various supplies in all parts of their districts.

This circular letter would have been more complete had it also directed attention to section 7 of the Public Health (Water) Act, which renders it obligatory on the part of

every rural sanitary authority from time to time to take such steps as may be necessary to ascertain the condition of the water supply within their district, and authorises the payment of all reasonable costs and expenses incurred by them for this purpose.

CHAPTER XX.

WELLS AND THEIR CONSTRUCTION.

The practice of obtaining water by means of wells sunk in the subsoil is one which dates from the remotest antiquity, and at the present time a very large proportion of the population of the globe derives its supply of water from such sources. In Great Britain it is estimated that over one-third of the population is so supplied. Whilst in every other department of engineering improvements have advanced with rapid strides, especially in recent years, shallow wells continue to be constructed in almost precisely the same way as they were thousands of years ago. The well-sinker is the most conservative of men, and in most districts it is impossible to get a well constructed so as to protect the water from pollution. To the country well-sinker a well is merely a reservoir to contain water, and whether this water enters from the bottom, side, or top he considers a point unworthy of consideration, and in fact he makes the well in such a manner that water can freely enter it at all points. The result is, that as wells are, for convenience, almost invariably sunk in close proximity to inhabited houses, impurities from the soil, from defective drains, cesspits, and cesspools readily gain access and foul the purer water which enters at a greater depth. It is not surprising therefore that the great majority of such wells yield water which is always impure, and liable at any moment to become specifically contaminated and produce an outbreak of disease. The time-honoured custom of

lining the well with bricks, set dry, and resting upon a wooden curb, still almost universally prevails. The brick-work may be carried right up to the surface and the well left open, or it may be covered with a lid, in which case it is frequently so left that the water spilt upon withdrawing the bucket runs back into the well, carrying with it filth from the surface of the ground around, and during a heavy rainfall the surface water runs directly into the well. Where the well is covered up, the cover is generally near the surface, and may consist of old railway sleepers or logs of wood admitting water freely. Even if no sewage matters enter such wells, the wooden curb and the rotting wooden covering yield putrid organic matter to the water. Draw wells and dipping wells are also liable to be contaminated by the dirty vessels let down into them, by frogs, rats, and other animals getting in, and by dead leaves and other matters blown by the wind. The animal and the vegetable substances by their death and decay foul the water. In wells otherwise carefully constructed it is often found that impure water can gain access along the track of the pipe leading from the pump to the well.

In a properly-constructed well no water should be able to enter except from near the bottom, so that before reaching the well it must have passed through a considerable thickness of subsoil, becoming in its course thoroughly filtered and purified. Various methods of accomplishing this difficult task have been suggested; but as there are other ways of obtaining subsoil water, which are more simple and far more satisfactory, we may reasonably hope that ere long the ordinary form of shallow well will be abandoned. Before describing these other methods, however, the best ways of constructing wells may be briefly referred to. Where the excavation is through solid rock, such as chalk, limestone, or sandstone, the steining, or lining with a cylinder of brickwork or of iron or other material will only be necessary to keep out the water from

the more pervious surface soil. If bricks be employed they must be well bedded on the rock with cement, and the whole of the brickwork lined inside with hydraulic cement, and the lining continued some distance below the last layer of bricks on to the exposed surface of the rock, so as to render the junction as impervious as possible. The brickwork should also be well puddled behind. Where the rock is not freely porous water may accumulate in the loose subsoil, and unless the greatest care be taken it will enter the well. In the most modern wells cast-iron or wrought-iron cylinders are employed for lining the upper portion in order to keep out the surface water and land springs. Similar cylinders are also employed to keep out water from fissures which may be met with in excavating the well. Where the subsoil is clay and impervious these precautions are of course not necessary. In ordinary wells, sunk throughout in a porous subsoil, the lining should consist of two separate rings of 4½-inch brickwork laid in cement and lined with cement to a depth of 10 or 12 feet from the surface. As this class of work is somewhat expensive, and the cement is liable to fracture, either by the inward pressure of the sides of the well or other causes, earthenware tubes are now being made by the Leeds Fireclay Company for lining purposes. The ground having been excavated as deep as can be done with safety, a tube is dropped in and some well-puddled clay laid on the bevelled edge and another tube lowered. If properly driven the tubes fit well together. The tubes are lowered by aid of ropes, blocks, and cross-bars. Having got in the tubes, a man can easily work inside and undermine the edge, when the weight will cause them to descend. Of course the joints are afterwards "pointed" inside with cement so as to make them more secure, and it is advisable to try all the tubes, fitting and marking them before using. Or the well may be constructed in the ordinary manner, dry steined with 4½-inch brickwork if necessary, and the tubes then lowered and

fitted and puddled behind with clay. Dry-steined wells at present in existence might with advantage be converted into tube wells in this manner. The well itself having been so constructed as to prevent the possibility of water entering anywhere except at the bottom, it remains still to cover it in and protect the top. The best plan is to project the dome of the well 6 or 12 inches above the surface of the ground and securely cover with a properly-fitting iron cover. By this means easy access is at any time gained for cleansing or examining purposes. The pump should be fixed some little distance from the well, and the drain carrying away the waste water should not go near it. Every care should be taken to render water-tight the aperture through which the pump pipe passes, and it should be bedded in clay or cement so as to prevent the water or rats forming a track alongside the pipe through which impurities can gain access to the water in the well. Probably the best plan is to solder a baffle plate to the suction pipe and imbed this plate in the side of the well. If the sides of the well be covered up to a sufficient height above the ground, the pump may be fixed inside, the handle and spout only projecting outside. A hooded aperture at the top can be left for ventilation.

Quite recently I have seen wells the upper portions of which were constructed from the halves of old steam boilers, the domed end of the boiler forming the top of the well and a hole being drilled through the side for the pump pipe to enter. To prevent the action of a soft water upon the iron, it is desirable that the whole of the interior should be lined with cement.

Koch, in his work on *Water Filtration and Cholera*, whilst condemning strongly the ordinary shallow well, recognises the fact that it is impossible to arrange that those already existing should be abandoned. He therefore recommends that the construction should be so altered as to remove all danger of contamination from above. "To achieve this,

one should proceed by filling up the well to the highest water point with gravel, and over the gravel with sand up to the very top." Of course an iron pipe should traverse the sand and gravel and be connected with the pump. A well so constructed "gives the same protection against the infection of water as is given by the sand filtration of the great waterworks. In fact it really gives a greater protection, since it is not exposed to the many disturbances in the process of filtration already referred to, and is also not affected by frost." So much attention is now being given to perfecting as much as possible the water supply of the great waterworks, that it is important not to lose sight of the domestic water supply by pumps and wells. By improving the wells in the manner explained above, "the spread of cholera,* in so far as it is due to water, can be restricted to a great extent. It is just in this respect that a great deal can yet be done." This suggestion of Koch's is one worthy of consideration, since the change can be effected at a minimum of expense, and the result leaves little to be desired. It is important, however, to remember that the superficial layer of sand should be at least 6 feet in thickness. Where the subsoil water is reached at a less depth than 6 feet, probably this method will not afford complete protection in many cases. Dr. R. Kempster, in his researches on "The influence of different kinds of soil on the cholera and typhoid organisms," arrived at the following conclusions: "White crystal sand, yellow sand, and garden earth have no marked favourable or injurious action on the life of the organisms. The length of life of the organisms in the soil depends chiefly on the amount of moisture present. Peat, on the contrary, is very deadly to both the comma and typhoid bacillus. The soil acts as a good filter, holding back most of the organisms, but it is possible for these organisms to

* And of typhoid fever and other diseases disseminated by water.

be carried through $2\frac{1}{2}$ feet of porous soil by a current of water." Where the ground water-level, therefore, is within 5 or less feet from the surface, the side of the well should be rendered impervious to a depth of 10 or 12 feet, or, better still, the water should be obtained by aid of an Abyssinian tube well, next to be described, driven to at least this depth.

In a great many instances subsoil water can be obtained without the trouble and expense of well-digging, merely by driving iron tubes through the ground until the subsoil water is reached, and fixing a pump to the upper end of the tube. Such tube wells were first used systematically during the Abyssinian campaign, hence they are now popularly known as "Abyssinian" tube wells. They are most suitable for gravel, coarse sand, chalk, and similar porous water-bearing strata, and for depths not exceeding 40 to 50 feet, though under exceptional circumstances tubes have been driven successfully to a depth of 150 feet. Naturally they cannot be driven through hard rock, neither are they suitable for obtaining water from marl, fine sand, or clay formations, since the apertures in the perforated terminal tube are liable to become blocked by the fine particles of which such strata are composed. A pointed perforated tube is driven into the ground by aid of a "monkey." (The tubes vary from $1\frac{1}{4}$ to 4 inches in diameter, according to the amount of water which it is desired to raise.) When this tube has been well driven, a second tube is screwed on to the first and the driving resumed. By lowering a plummet down the tubes from time to time, it can be ascertained whether water has been reached or whether sand or earth is filling up the end of the perforated tube. When water is reached a pump can be attached and a sample drawn for examination, and the quantity available ascertained. If either the quantity or quality be unsatisfactory, the tubes can be driven deeper, or they can be withdrawn and redriven in another spot. A well of this

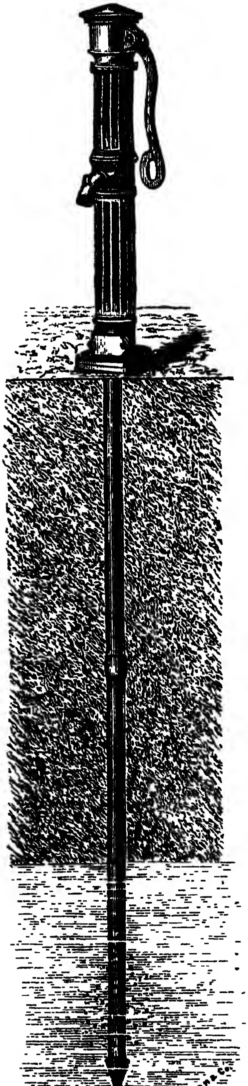

FIG. 20.—Abyssinian Tube Well.

character is shown in Fig. 20. Very often, where the supply from an ordinary sunk well is limited, it can be increased by driving one or more of the " Abyssinian " tubes from the bottom of the well. Special pointed and perforated tubes are employed where the soil is ferruginous or likely to corrode the metal of the ordinary tube. Tubes designed to prevent plugging with sand are useful under certain circumstances, as when the water-bearing strata contains together with the sand a fair proportion of grit. In fine sandy soils, however, it is better to withdraw the tubes, ram down a lot of fine gravel, and redrive.

In the " Abyssinian " tube well the water is drawn directly from the water-bearing stratum, there being no reservoir. At first the water invariably contains fine sand or chalk, according to the nature of the subsoil, but after a time a clear water is yielded. This is probably due to the removal of all the fine particles and débris from around the terminal tube and the formation of a natural cavity in which the water accumulates. In suitable localities these tube wells answer admirably, and not only are cheaper to sink, but yield a safer supply of water than a sunk well. 'One

man, usually, can drive the smallest-sized tubes, but three or four men are required for the largest tubes. In very light soil a 30-feet well may be driven in less than one day; in a firmer soil three days may be required. Whatever the depth of the tube well an ordinary pump will raise the water, provided the water level in the tube is within 25 feet of the surface. If the water stand at a lower level, a deep well pump must be provided.

The capacity of these tube wells varies with the depth, yield of spring, and power of pump applied.

The following are the estimates of two of the best-known firms of well-sinkers:—

Size of Well.	Yield in Gallons per Hour	Authority.
1¼ in.	150 to 600	Le Grand and Sutcliff
2 ,,	300 to 1,200	,, ,,
3 ,,	600 to 2,400	,, ,,
4 ,,	1,200 to 4,400	,, ,,
1¼ ,,	150 to 900	C. Isler and Co.
2 ,,	300 to 1,500	,, ,,
3 ,,	450 to 3,000	,, ,,

Messrs. Le Grand and Sutcliff have kindly furnished me with the following table (see page 372), giving the depth of well, size of tube, yield of water per hour of a series of typical wells driven by them, which bear out the above statements.

Not only are these tube wells preferable to sunk wells on account of the greater freedom from risk of contamination, but they are much less expensive. The probable cost of a well can easily be calculated from the following estimates (see page 3[illegible]).

TABLE X.

"Abyssinian" Tube Wells (Norton's Patent).

Town.	Water-bearing Stratum.	Water Level.	Depth.	Diameter.	Yield per Hour in Gallons.	Sunk by	Date.
Beccles	Chalk	4′ 0″	84′	3″	3,000	Le Grand and Sutcliff	1879
Burnham, Essex	Sand and Gravel	23′	28′	3″	1,800	,, ,,	1899
Burton	,,	17′	25′	3″	2,400	,, ,,	1878
Chelmsford	Gravel	23′	33′	2″	720	,, ,,	1896
Dagenham	Sand and Gravel	9′ 6″	17′	1¼″	480	,, ,,	1898
East Stratton	Chalk	20′	34′	1¼″	480	,, ,,	1898
Gravesend	Sand and Gravel	10′	54′	2″	1,200	,, ,,	1879
Hereford	Gravel	17′ 6″	33′	3″	1,900	,, ,,	1881
Ilford	Chalk	4′	80′	2″	1,200	,, ,,	1896
Lechlade	,,	10′ 6″	22′	3″	3,000	,, ,,	1892
Lincoln	Sand	4′ 6″	31′	3″	2,000	,, ,,	1894
Melton Mowbray	Gravel	4′ 6″	36′	3″	2,000	,, ,,	1880
Millwall	Sand	4′	20′	3″	2,400	,, ,,	1884
Musselburgh	Gravel and Sand	8′	20′	3″	1,800	,, ,,	1886
New Ross	Gravel	5′ 6″	29′	3″	2,000	,, ,,	1885
Purfleet	Chalk	1′ 0″	70′	2″	1,600	,, ,,	1886
Rainham	Sand	14′	45′	2″	780	,, ,,	1899
Rotherhithe	Gravel	11′ 0″	26′	3″	1,560	,, ,,	1885
Swansea	,,	17′	29′	3″	1,500	,, ,,	1893
Widford	Chalk	4′	79′	2″	1,500	,, ,,	1890
Witham	Sand and Gravel	11′ 6″	18′	1¼″	480	,, ,,	1898
Wraysbury	Sand	7′ 6″	18′	2″	1,200	,, ,,	1891

	Twelve-Feet Tube with Hire of Plant and Man to Superintend Driving.	Add for each additional Foot.	Pump, Column, and Foundation.
1¼-inch tube	£2 4 0	3s.	£2 10 0 to £3 10 0
2 „	3 10 0	4s. 6d.	„ „
3 „	7 10 0	10s.	£3 10 0 to £4 10 0
4 „	9 15 0	13s.	„ „

To the above must be added the man's time in travelling, railway fares, carriage of materials, etc. A well recently driven in one of my districts to a depth of 17 feet, a 2-inch tube being used, cost £8 12s. 4d., the items being as under.

17-feet 2-inch tube well	£2 14 6
4-inch column, pump, and foundation . . .	3 8 0
Hire of man and plant	1 10 0
Man's time travelling	0 7 6
Railway fare and carriage	0 12 4
Total . .	£8 12 4

The wages of the agricultural labourer who assisted in driving the tube is not included, but would not exceed 5s.

These prices may be compared with the following schedule of prices taken from Sir R. Rawlinson's *Suggestions as to the Preparations of Plans for Drainage and Water Supply* (Local Government Board, 1878).

Schedule of prices for sinking wells in Clay, lined with 9-inch brickwork in Portland Cement. Wooden curves, cylinders, and pumping extra.

4 feet diameter	to depth of	200 feet,	50s.	per foot run
5 „	„	200 „	65s.	„
6 „	„	200 „	85s.	„
7 „	„	200 „	105s.	„

Rough estimate of well-sinking, through Clay, Chalk, and Gravel, entirely *exclusive* of brickwork or fittings.

Diameter of Well.	Depth.	Price per Foot of Depth.	Total Cost.
4 feet	50 feet	3s.	£7 10 0
5 ,,	50 ,,	4s. 6d.	11 5 0

Where hard rock has to be pierced or where the water-bearing stratum lies at a considerable depth below the ground surface, the well must either be excavated or bored. The cost of sinking as compared with boring is so excessive that nearly all deep wells are now bored. Not only is the cost much less, but as the bore-hole is lined with metal tubes (which should be of wrought iron, lap-welded and steel-socketed), surface springs are excluded, and the possibility of contamination reduced to a minimum. Various methods are employed and many different kinds of tools, according to the nature of the strata to be penetrated, and the depth and the manner of the borings, which vary from 3 to 18 inches in diameter; but in soft rock, like chalk, this diameter may be greatly exceeded. In the majority of cases the borings are made from the bottom of a dug well, the object usually being twofold: (*a*) to form a storage reservoir for the water; and (*b*) to provide a receptacle for the pumps. It is, however, found that in many cases the dug well can, with advantage, be dispensed with. It is only really necessary where the spring is weak and the demand for water intermittent. Such dug wells, unless very carefully constructed, also increase greatly the liability to contamination by surface water. During the process of boring a number of springs may be tapped, and the quality of the water yielded by each can be ascertained by analysis. If it be ultimately found that one of the upper springs yields the most suitable water, the tubes can be withdrawn and the hole plugged at such a depth

that only water from that particular spring is supplied. In the older wells the tubes lining the bore are usually not continuous, and water from divers sources has free access to the wells. In the more modern borings larger tubes are used for convenience in boring, and a smaller tube with tight joints is then inserted, reaching from the surface to the bottom of the well. The outer tubes may be afterwards withdrawn or the space between the two filled in with cement. With such a continuous tube the pump can be so attached that the water is drawn directly from the bottom of the well. The conditions which influence the yield of water from bored wells are so lucidly expressed by Mr. R. Sutcliff, in a paper read before the Brewers' Congress in 1886, that no apology is required for reproducing them here. "The continuous tube," says Mr. Sutcliff, "has an important bearing on the yield from the spring; the weight of the atmosphere being removed by the pump from the surface of the water in the tube well. This, as regards the velocity of the flow of the spring, is equivalent to drawing the water from some 34 or 35 feet lower than is possible when the weight of atmosphere presses on the surface of the water. The increase in supply under these conditions is equal to about 40 per cent., which acts as an important compensation for absence of storage. It may be interesting to give an example of this. A dug well, 25 feet deep and of 5 feet diameter, will hold 3,050 gallons of water. Suppose that such a well is supplied by a spring which, when the head of 25 feet is removed from it, will flow at the rate of 950 gallons per hour. As the maximum flow is only obtainable after the storage is completely exhausted, the average yield must be taken until that exhaustion occurs. Let the pumps be started to draw 1,500 gallons per hour, the quantity obtained by the storage will be exhausted in two hours. But as in that time the spring would have been yielding an average flow of, say, 700 gallons per hour, the

well would not be emptied until the pumps had been going about four hours. When that time had expired, the spring would be yielding its maximum of 950 gallons per hour, and the speed of the pumps would have to be slackened proportionately. Under these conditions, a total of 11,500 gallons would be drawn from the well in ten hours.

"Let a tube well be placed under exactly similar circumstances as regards supply and water level. The pumps drawing from a tube well could get 950 gallons per hour plus 40 per cent.; that is to say, 1,330 gallons per hour. Therefore, the tube well would in 10 hours yield 13,300 gallons—a gain, in that time, in spite of absence of storage, of 1,800 gallons; and the pumping from the tube well could be continued uniformly at the same speed for an indefinite period, so long as the spring maintained its flow.

"When the normal level of the spring is not sufficiently near the surface, or the flow is not rapid enough to enable an ordinary lift pump to draw the water, the tube well must be made of such size as will enable a deep well pump to be placed in it, as far below the surface of the water as may be necessary to obtain the required supply. A deep well pump can be placed 150 or even 200 feet below the surface; but when it becomes necessary to place it at that depth below the water level, the supply required is one that is very great compared with the spring that yields it. Because, although all springs increase until the base of them is reached, that augmentation is a constantly decreasing one. The reason for this decrease is obvious. The water flows through channels of fixed area. When the head of water is removed, the pressure is increased proportionately with the depth that the water is lowered; but the friction of passing through the channels also increases. So that to double the supply that flows at 150 feet below the head of the spring, it would be necessary to place the pump 600

feet under water. These facts are of the highest importance in deciding whether a given spring can meet the requirement of the consumer. Let it be supposed that two borings are made, and that springs are tapped by these borings, which both overflow the surface of the ground at the rate of 10 gallons per minute. To the casual observer both of these springs might be considered as equal. But one might be ten times stronger than the other. Let us call these springs A and B. The spring A, when we lower by pumping, gives no appreciable increase; whereas the spring B, when we lower it only 3 feet, yields double the quantity of water. Why is this? If it were possible to carry the pipes up from which spring A flows, we should find that the water would rise 100 feet before it came to rest; whereas with spring B, if we only piped it 1 foot higher, it would cease to flow. This would prove that spring A is a high-pressure one, the source of which is 99 feet above the ground level; but spring B has its source only about 1 foot above the ground level. The channels of communication in spring A are small, and the friction is depriving us of the advantage of the great head of water. The channels of communication from spring B are free and large. One may, however, be deceived unless the test of pumping is a prolonged one. What is known as a 'pocket of water' may appear from temporary pumping to be a spring of the B class; but sustained pumping will demonstrate the impostor, as the water level will not recover itself without a more or less prolonged period of rest. This proves that while the channels of communication are large, the area which is being drawn from is small. Under such circumstances a multiplication of wells would be of no advantage; but in many instances the friction of drawing water through the earth may be largely diminished by sinking a number of tubes and coupling them together, so that one pump draws from them. What is known as the 'cone of depression' is reduced by this method of drawing the

water. Tubes placed, say, 20 feet apart, may each only yield a small supply; but the aggregate obtained from a number of these tubes becomes very large.

"At the Burton Breweries, some forty or fifty 3-inch 'Abyssinian' tube wells yield 2,000,000 gallons daily; yet no one of the 3-inch tubes delivers more than 2,000 gallons per hour. The area from which they draw is so extended that at no one point is the water level materially depressed.

"At the Town Waterworks of Watford, a dug well of 10 feet diameter, supplied by a 12-inch boring at the bottom, of it, proved inadequate when drawn from night and day to meet the requirements of the town. A single tube well of $8\frac{1}{2}$ inches in diameter, placed some 30 feet from the dug well, doubled the supply of water obtainable, and thus enabled the hours of pumping to be materially reduced. Somewhat similar experiences were obtained at the Town Waterworks of Aldershot, Hertford, St. Albans, and Abbots Langley, all of which towns now derive their water supply from tube wells."

The imperfect construction of many of our older wells to some extent brought boring into disrepute. Thin sheet-iron was in many districts used for lining the bore. The imperfect joints very frequently admitted of the entrance of subsoil water, hence the water yielded was often polluted. In a comparatively few years the sides of the tubes corroded and collapsed, and the supply gradually, or, in some cases, suddenly failed. By the use of proper casing, such as the "Russian Brand" swelled and collar-joint casing, employed now so extensively, all these defects are obviated. The difficulty, however, of making these tubes absolutely water-tight is greater than at first would be anticipated, and where the slightest defect exists the continued raising of water by pumps fixed directly upon the bore tube is very likely to accentuate it by the continued lateral insuction of air and water. A most instructive example of such a defect is contained in Dr. Geo. Turner's *Report on the Water*

Supply to the Suffolk County Lunatic Asylum, previously referred to. Some years ago the prevalence of dysentery in this Asylum was attributed to the impure water supply, and a fresh supply was obtained from two bored wells, so constructed that contamination of the water appeared quite impossible. Dr. Turner says, "The construction of these bores is very similar in principle, but varies slightly in detail. In both instances an 8-inch steel pipe with screw joints was sunk into the chalk, the bore was then enlarged, filled with cement, and the 8-inch tube sunk into the cement, which was then allowed to set. After the cement had set, a 6-inch steel tube, also with screw joints, was passed through the cement to a distance of 200 feet, when the bore was again enlarged; the cavity was filled with cement, which was allowed to set, and then the boring was continued another 100 feet. The total depth of the bores was 305 and 350 feet respectively. The space between the 8-inch and 6-inch tubes was filled with cement through a composition pipe passed to the bottom, and the bore was fastened to the pump by an air-tight joint." Notwithstanding these elaborate precautions, dysentery again broke out in the Asylum, and was again traced to the water supply. Dr. Turner found that after continued pumping there was a marked difference in the quality of the water drawn from the two wells, and upon excavating around the tubes and pouring into the excavation a solution of chloride of lithium, he afterwards found distinct traces of this salt in the water drawn from the pumps. From the result of these and other experiments he concluded that there was no reasonable doubt that neither of the tubes was water-tight. The danger of lateral insuction must be greater in wells in which the pump is screwed directly on to the lining tube, than in those in which the pump pipe or barrel is merely inserted within the lining tube, since the removal of the atmospheric pressure, in the former case, causes water or air to enter the bore through the most minute

apertures, and in course of time such apertures enlarge, admitting impurities more and more freely. This danger, in some degree, counterbalances the advantages of the increased supply, and it would appear to be safer not to directly connect the pump with the bore tube where water can be obtained in sufficient quantity without such attachment.

The cost of constructing bored wells varies with the nature of the strata which have to be pierced. Fifty years ago, local well-sinkers in Essex would pierce 300 feet of London clay, line the well, and fix a pump for a total cost of less than £100. At the present time similar wells cost about three times that amount, and the local well-sinker has disappeared. The only explanation appears to be that it has been found more economical to employ professional well-borers, and pay treble the price for a properly-constructed well, than to employ the local men. Sir R. Rawlinson, in his *Official Report to the Local Government Board on Water Supplies, etc.*, gives the following schedule of prices for making bore-holes in red sandstone. The prices for boring in chalk and in sand and clay average 1s. per foot less, but in sand and clay, where the boring exceeds 200 feet in depth, the price is, on the contrary, about 3s. per foot more than for boring in chalk or sandstone.

Diameter. Inches.	Per Foot Run.				Cost of Cast or Wrought-iron Pipes per Foot.
	First 100 Feet.	Second 100 Feet.	Third 100 Feet.	Fourth 100 Feet.	
3 or 4	5s. 6d.	7s. 6d.	11s. 6d.	14s. 6d.	4s. to 5s. 6d.
5	7s. 6d.	10s. 6d.	13s. 6d.	20s. 6d.	6s. 6d.
6	8s. 6d.	11s. 6d.	14s. 6d.	20s. 6d.	7s. 6d.
8	9s. 6d.	12s. 6d.	16s. 6d.	22s. 6d.	10s. 6d.
9	12s. 6d.	15s. 6d.	20s. 6d.	25s. 6d.	11s. 6d.
10	13s. 6d.	16s. 6d.	21s. 6d.	26s. 6d.	13s.
12	17s. 6d.	21s. 6d.	25s. 6d.	30s. 6d.	18s. 6d.

The following schedule of prices for borings from the surface from 3 to 12 inches in diameter, is exclusive of lining tubes but includes all labour and necessary plant. The prices quoted are per foot.

	Messrs. Le Grand and Sutcliff.		C. Isler and Co.	
	Boring in Alluvial and other Free-boring Strata.	In blowing Sand, Rock, Stone, and other hard or difficult Strata.	Gravel, Clay, Sand, or other soft Strata.	Rock or Stone.
Not exceeding 100 ft.	7s. to 14s.	15s. to 50s.	8s. to 20s.	20s. to 40s.
,, 200 ft.	12s. to 24s.	20s. to 70s.	13s. to 30s.	25s. to 50s.
,, 300 ft.	16s. to 30s.	25s. to 70s.	18s. to 40s.	30s. to 60s.
,, 400 ft.	20s. to 40s.	30s. to 80s.	23s. to 50s.	35s. to 70s.
,, 500 ft.	30s. to 50s.	35s. to 90s.	28s. to 60s.	40s. to 80s.

The wrought-iron, lap-welded, steel-socketed tubes vary in price with the fluctuations of the market, but the following are recent estimates:—

3-inch internal diameter, $\frac{1}{4}$ inch thick,		4s.	per foot
4 ,, ,, ,, ,,		5s.	,,
6 ,, ,, $\frac{5}{16}$,,		9s. to 10s.	,,
$7\frac{1}{4}$,, ,, ,, ,,		11s. to 13s.	,,
$8\frac{1}{2}$-inch diameter and $\frac{5}{16}$ inch thick,		15s. to 17s.	,,
10 ,, ,, ,,		18s. to 20s.	,,
$11\frac{1}{2}$,, $\frac{3}{8}$,,		23s. to 25s.	,,

The approximate depth at which water may be reasonably expected to be found, and the nature of the strata to be penetrated, being known, the cost of constructing a bored well can be ascertained from the above data. An estimate of the amount of water which the well will yield can only be given by those who have made a special study of the hydrology of the district.

The tables on pp. 383-4 give the details of a number of

District..	Depth.	Yield per Day.	Temp. of Water.	Cost.
Barcaldine . .	691 ft.	175,000 galls.	102° F.	£1,340
Blackall . .	1,663 ,,	300,000 ,,	119° F.	5,074
Charleville . .	1,571 ,,	3,000,000 ,,	106° F.	3,525
Cunnamulla .	1,402 ,,	540,000 ,,	106° F.	2,316
Muckadilla . .	3,262 ,,	23,000 ,,	124° F.	7,382
"65-mile bore" .	2,362 ,,	104,000 ,,	...	3,073

About 715 public and private wells have been sunk, varying in depth from 86 to 2,484 feet. The number of unsuccessful borings is not stated. The water is derived from the lower cretaceous formation, and most of the wells overflow. The largest yield is from a private bore in the Warrego district. The well is 1,502 feet deep, and yields 3,500,000 gallons of water daily (112° F.), at a pressure of 200 lb. to the square inch. The yield at the present time from all the wells is estimated at over 200,000,000 gallons per day. The flow of a large proportion is uncontrolled, and most of it wasted. A bill was recently introduced to regulate the flow from these bores and prevent the lowering of the pressure (water level), but it was thrown out by the Upper House. Regulating valves are used for all the Government bores.

In *South Australia* it is estimated that the area of the water-bearing chalk basin is nearly 100,000 square miles; but the number of wells bored at present is inconsiderable. Water has been obtained at depths varying from 237 to 1,220 feet, the temperature ranging from 81° F. to 90° F., and the yield from 48,000 to 1,200,000 gallons daily. In some wells the water rises considerably above the surface; in others it does not reach the outlet of the bore.

In the *Colony of Victoria* the Government has expended some £50,000 in making experimental bores, but apparently with little success. In some cases the rocks were pierced to a depth of over 2,000 feet without water being discovered; in others the water obtained was unfit for domestic

purposes, whilst in the few successful bores the water level was far below the ground surface and the supply limited. One instance is recorded in which the saline constituents of the water acted so powerfully upon the iron lining of the bore as to destroy its continuity within eighteen months.

New South Wales.—In 1892 Mr. Boultbee, the Officer-in-Charge for Water Conservation, issued a report on Artesian boring, containing sections and descriptions of all the Government bores. The bores when decided upon are let by tender, the work being done under official supervision. Mr. Boultbee gives a list of twelve completed borings, and refers to 40 other bores in progress. Particulars are also given of forty-five private bores. The wells vary in depth from 53 to 2,000 feet. Two borings appear to have been unsuccessful; the remainder yield from 24,000 to 2,000,000 gallons of water per day. Most of the private wells are from 700 to 1,000 feet deep, and the flow varies from nil to 1,728,000 gallons daily. The tenders for the Government bores varied from 24s. to 27s. per foot for the first 1,000 feet; from 27s. 6d. to 32s. 6d. for the next 500 feet, and from 30s. to 40s. for an additional 500 feet, exclusive of casing. The contractor finds all plant, tools, labour, etc., but the Government does all the carting and supplies the casing. The average cost of the bores per foot, including casing, is said to be 37s. All the Government bores, and some of the private bores, have valve arrangements for regulating the flow, but Mr. Boultbee believes that some 16,000,000 gallons of Artesian well water runs daily to waste, and he recommends legislation to prevent this. Imperfect casing is also probably the cause of serious waste, and this he thinks should be dealt with by legislation, as is already done in some of the North American States. The chalk basin yielding water is estimated to have an area of 40,000 square miles. Over the catchment area supplying this basin the average rainfall is 22 inches, and only about $1\frac{1}{2}$ per cent. of this finds its way into the rivers. It

is assumed, therefore, that 50 per cent. of the total rainfall percolates and is recoverable by means of wells and bores. As the catchment area is only about 13,000 square miles in extent, the water from the bores should not be sufficient to irrigate more than about one-sixth the area of the chalk basin. Mr. Boultbee believes that if further operations are equally successful, it will be "difficult to estimate the progress and prosperity that must naturally ensue." The few analyses given show that some of the wells yield strongly saline water, and others, water which is strongly alkaline, such as is derived from the chalk in certain portions of Essex. The Government Veterinarian, reporting on saline waters, says, "It is easy to understand that starving, or even thirsty travelling stock may suffer disastrously from drinking at once a large quantity of water containing a high percentage of saline material. Horses and cattle will drink from 5 to 12 gallons a day, sheep from 1 to 2 gallons a day. Drovers should be cautioned at saline drinking-places of the danger of permitting stock to drink too freely, until they have become accustomed to the medicinal properties of the water."

Cape of Good Hope.—The Government Inspector of Water Drills, in his report for 1893, says that the work undertaken by the Government has been an unqualified success, but the geological formation in many parts of the colony is such as not to be "conducive to the existence of Artesian areas of any great extent. A great portion of the colony, known as the Karoo, however, contains many such areas, and here prospecting for water has been most successful. This district is composed of a series of areas formed by a network of intrusive igneous dykes, chiefly of a dolerite nature, cutting through the sandstone and shales and acting as intercepting barriers to the underground water. Since the commencement of operations in May, 1891, out of a total of 341 holes bored, water was

tapped in 289 and overflowed from 128. The average depth was only 43 feet per hole, and the deepest bore was only 227 feet. The flow from the 128 bore-holes is estimated at 2,332,000 gallons daily, or an average of about 18,000 gallons per well. In several cases the flow has decreased; in others it has increased. The Inspector thinks that there is little fear of exhausting the underground reservoirs, since moderate-sized towns, such as Colesburg, Victoria West, Hanover, Veuterstad, and Bristown, "boast of perennial streams, issuing from one or two bore-holes in each case, sufficient to supply their domestic wants as well as to irrigate numerous erven." The Inspector recommends that where the water does not overflow, 4-inch bores should be made instead of 2-inch as at present, and to such a depth as will ensure a 50-feet head of water from which to pump. With a deep-well pump and windmill, practically inexhaustible supplies could be obtained from such wells at a nominal cost. A few very deep wells have been bored (up to 1,200 feet), but the results are not encouraging. In Bushmanland and Bechuanaland, where the general geological formation is gneiss and granite, the rock can only be pierced by the diamond drill, and the wear and tear of the diamonds is severe. As the water lies in the rock fissures at but a slight depth, the rock is better penetrated by means of blasting.

In the *United States* a special Department at Washington collects information with reference to all wells bored, and in several states Acts have been passed to encourage the sinking of Artesian wells, and for preventing waste of the water flowing therefrom. The number of such wells is simply enormous. In the Utah Territory there are nearly 2,000; in the San Joaquin Valley, California, about 3,000; in the San Louis Valley, 2,000; in Deseret, 2,000, etc. In Kern County, California, within an area of 18 by 14 miles, there is a group of wells yielding 61,000,000 gallons of water daily. To the development of well-boring

the reclamation of the Great American Desert is in great part due. Enormous tracts of land, over which the annual rainfall is only from 2 to 6 inches, are now irrigated by the water overflowing from Artesian wells.

In *Algeria and Sahara* the French engineers have during recent years been engaged in reclaiming the deserts by means of water derived from deep bores, and it is stated that the flow from the wells already sunk is about 100,000,000 gallons daily, and that the effect produced upon the sandhills by irrigation is amazing.

In *Argentina and Uruguay* a drilling company has recently sunk a number of wells, and last year the Buenos Ayres and Rosario Railway Company drove an Abyssinian tube well to a depth of 200 feet, and obtained an abundant supply of water.

In arid regions, and where the rainfall is fitful, water can often be obtained for irrigation purposes by boring, and it is probable, now that increased attention is being drawn to this method of obtaining water, many districts at present uninhabitable will become both populous and prosperous. In certain of our Colonies it may safely be asserted that the discovery of these subterranean sources of water will ultimately conduce to far greater prosperity than the discovery of gold.

In all attempts to obtain water by sinking wells, the following facts should be borne in mind. Sand or gravel resting on chalk will yield no water, unless the chalk also is penetrated to below the plane of saturation; that chalk contains immense volumes of water, but almost exclusively in the fissures. Wells or borings sunk in very solid chalk may yield no water, the more fissured the stratum and the greater the yield that may be anticipated. The tertiary sands between the London clay and the chalk yield only a moderate quantity of water. The impermeable beds of Purbeck and Portland stone often contain a considerable amount of water in their fissures, but under the latter rock

water may be found in the porous stratum between it and the clay beneath. Limestone is only slightly porous, and the water contained therein is probably chiefly found in the fissures. The lower oolite contains large quantities of water held up by the impervious beds of the lias. In the magnesian limestone water is only found where fissures are struck, but in this and the mountain limestone the water may be very abundant. In fissures of the metamorphic rocks, water also may be met with in the fissures if the sinking or boring is fortunate enough to strike such; but as the stratification is usually very irregular, the result of a boring can never be with safety predicted.

CHAPTER XXI.

PUMPS AND PUMPING MACHINERY.

Numerous varieties of pumps are now manufactured for raising water, and each probably possesses some advantages over the others under certain conditions. A pump which under one set of circumstances will work effectively and economically, may under other circumstances be ineffective or extravagant. Where large quantities of water have to be raised, the selection of a pump is of the highest importance, and it is only when the duty which it will have to perform and the exact conditions under which it must work are fully known that the selection can be satisfactorily made. All the varieties in ordinary use can be classified under the four following types—(*a*) Lifting pumps, (*b*) Plunger or force pumps, (*c*) Centrifugal pumps, and (*d*) Air Lift pumps.

(*a*) The commonest form of pump, the atmospheric, is the simplest form of this type. The essential part is the barrel, which is truly cylindrical and carefully bored and closed at the bottom by a valve opening upwards. Within the barrel works a piston or bucket, fitting the cylinder accurately, which is also provided with a valve opening upwards. When the piston ascends, the atmospheric pressure is removed from the surface of the lower valve, and water ascends through the so-called suction pipe, ultimately entering the pump barrel. When the piston descends the lower valve closes, and the water is forced through the valve in the piston, and at the next up-stroke

is discharged from the pump. The height at which the pump barrel may be fixed above the surface of the water to be raised obviously depends chiefly upon the atmospheric pressure. At sea-level this corresponds to a column of water about 34 feet high. As the valves and piston, even with best workmanship, are not perfect, such a pump cannot be depended upon to raise the water more than 27 feet. The vertical distance between the level of the water to be raised and the highest point reached by the piston must not, therefore, exceed this distance. Where the water-level fluctuates care must be taken to measure from the lowest level reached during these fluctuations, otherwise the water may at times fall so low that the pump will cease to act. This form of pump is only suitable for hand power and for use where it is not inconvenient to raise the water as required. For shallow wells it is almost universally employed, the water discharged from the pump barrel passing directly or through a very small reservoir to the outlet. In another form the upper portion of the body of the pump is elongated, or a pipe is connected therewith, into which the water rises with every stroke of the piston. As each stroke not only has to overcome the atmospheric pressure, but has also to raise this column of water, it is evident that the height to which water can be so raised by hand power is limited. About 30 feet is the highest to which water can be conveniently raised by one man. When other motive power is employed it may be raised by such a pump to about 100 feet above its source. This limit, in actual practice, is probably due to several causes, of which the principal is the uncertain action of the piston valve under such great pressure. In deep wells, where the water-level is more than 24 or 25 feet from the surface of the ground, the pump must be fixed within the well, the piston rod being lengthened so as to be connected with a lever or handle, or to a fly-wheel. In such cases it is usual to fix a double-barrel pump, since it is easier to raise a given

volume of water with such a pump than with a single-barrel of capacity equal to the two together. With the double-barrel the work is distributed, each half-turn raising one piston, whereas, with the single-barrel the whole lift is on one half turn. With a treble pump the work is still more equally distributed; but as complications are introduced the double-barrel is generally preferred.

The pump need not be fixed over or even near the well; but if at any considerable distance, it must be remembered that a certain amount of friction is introduced, and must be allowed for. The suction pipe must fall all the way from the pump to the well, otherwise air may lodge in the bends and impair the action of the pump. In long suction pipes it is desirable to have a foot valve to retain the water when the pump is not in use, and to prevent the concussion caused by the sudden arrest of the motion of the long column of water at each down-stroke of the piston; a vacuum vessel also should be connected with the pipe just before it enters the pump.

In another form of lift pump a solid piston plays in a barrel placed alongside a second barrel, which is closed at each end by a valve opening upwards. The upper end of this second cylinder is continuous with the rising main, whilst the lower end is continued into the suction pipe The upper end of the pump barrel is connected by a wide tube with the valve cylinder. When the pump is in action depression of the piston causes a vacuum in the barrel within which it works, into which water rises through the valve at the upper end of the suction pipe. When the piston is raised this water is forced through the upper valve into the rising main. A pump of this character can raise water a height of 700 feet and upwards.

(*b*) In the plunger or force pump a solid plunger takes the place of the ordinary piston or bucket, but the suction pipe, valves, and rising main resemble in arrangement the pump just described. The cylinder, however, in which the

plunger works is connected with the valve box by an opening near its base, and the plunger does not accurately fit the cylinder in which it works. When pumping is in operation the water rises in the suction pipe to fill the vacuum produced by the rising plunger, and when this falls it forces into the rising main an amount of water equal to the volume of the plunger which enters the cylinder. This single-acting plunger pump is largely employed for raising water to considerable heights. It is obvious that in this form of pump also the vertical length of the suction pipe must not exceed 27 feet. As a matter of practice the pump barrel is usually only a few feet above the surface of the water to be raised. Two or three such pumps may be combined, and so arranged that the discharge, instead of being intermittent, as in the single-barrel pump, becomes practically continuous. For high lifts and heavy pressures air chambers must be connected with these pumps. The water being forced into these instead of directly into the main, the compressed air acts as a cushion, and tends greatly to equalise the flow of water and relieve the valves from undue shock. The force pump is less troublesome to keep in repair than the lift pump, since it dispenses with the bucket, the clack valve of which can only be reached for repairs by taking the pump to pieces. Whilst the pump barrels are usually fixed vertically, they are occasionally placed in a horizontal position. In waterworks where water has to be raised from a well, and then forced to a considerable elevation, usually two sets of pumps are employed, one raising the water from the well to a reservoir at or near the ground-level, and the other forcing the water from this reservoir to the highest point at which the water is required.

(*a* and *b*) The so-called bucket and plunger pump, which is probably most extensively used for high lifts, combines in its construction both principles *a* and *b*, acting both as a lift and plunger pump. The piston rod working within

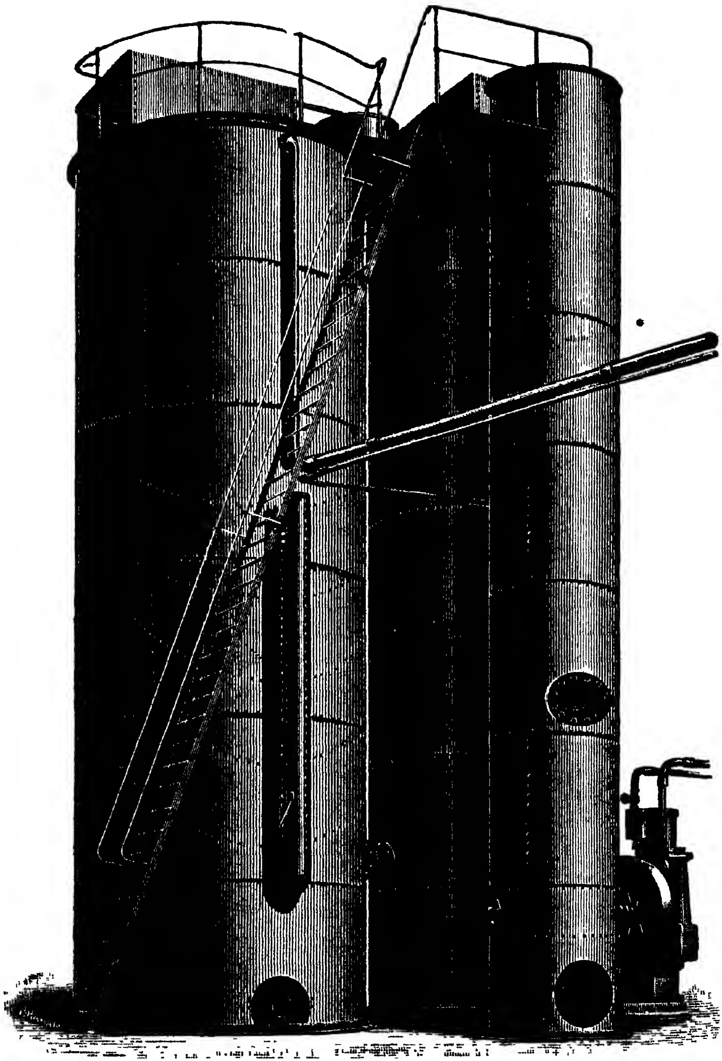

Fig. 18.—The "Stanhope" Water Softener.

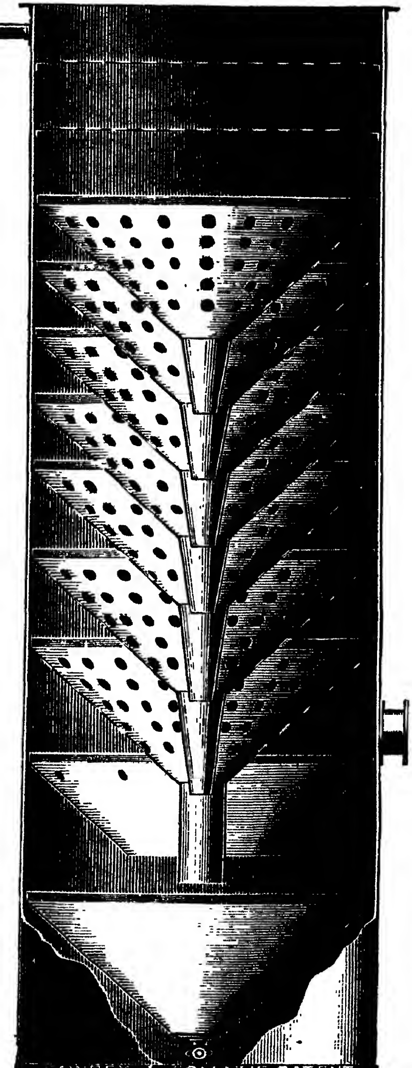

Fig. 19.—The "Stanhope" Water Softener (Clarifying Tower).

are introduced, and after chemical action has taken place the mixture passes at the bottom into the other, which acts as a "subsidence filter." The lime and other chemicals are contained in two smaller tanks placed above the larger, and which are used alternately. By means of floats, cocks, and nozzles, the portions of the chemical solution and of the hard water to be softened can be regulated. No agitator is required, and the deposited carbonates are removed by occasionally turning the sludge taps at the bottom of the hoppers.

At Stroud Waterworks the water is softened and clarified by a very simple modification of Clark's original process, all filtering machines being abandoned. By aid of a small water wheel, driven by the water to be treated, two pumps are worked, one raising lime water and the other the hard water. By altering the length of the stroke the proportion of the two can be adjusted, and as the rapidity with which the wheel rotates depends upon the pressure of the water in the mains, the relative quantities of lime water and hard water pumped remain constant. The treated water is clarified by subsidence in large settling tanks. The machine above referred to will soften 1,000,000 gallons of water per day, but the amount actually softened is only 300,000 gallons.

Messrs. Archbutt and Deeley have recently devised an apparatus which they regard as having many advantages over others in the market, especially for treating waters containing magnesia salts. The chemicals used (lime and soda ash) are boiled with water and then mixed with the hard water, contained in a tank, by means of a steam "trajector." After thorough mixing, steam and air are forced by a "blower" through perforations in a series of pipes laid close to the bottom of the tank. This stirs up the mud and diffuses it throughout the water, and when the liquid is allowed to rest precipitation is very rapid. In from thirty minutes to one hour the water is almost

perfectly clear and can be drawn off. By using duplicate tanks, one quantity of water can be treated whilst that in the other is undergoing clarification. Water which contains magnesia compounds, after precipitation, still contains a little carbonate of magnesia, which rapidly blocks up the boiler "injector." To obviate this the water, when being drawn off from the settling tank into the storage tank, is dosed with carbonic acid gas by aid of a blower. The carbonic acid is derived from the combustion of coke in a special stove. The water when sufficiently carbonated no longer deposits in the tubes. By this process the labour involved is no greater for softening 20,000 gallons than for 2,000, and with large quantities the expense for labour is said not to exceed ¼d. per 1,000 gallons. Some waters are found to clarify much more rapidly if a little alum be added, together with the other chemicals, and this the inventors recommend in such cases.

The cost for chemicals required to soften waters of various qualities is given in the following table by Messrs. Archbutt and Deeley, and is quoted here, since the chemicals used in this process are the same, both in quality and quantity, as those used in other processes which are designed to soften water containing both lime and magnesia. It will be observed that the cost increases rapidly with the amount of sulphates present, especially sulphate of magnesia, since such water can only be softened by use of soda ash as well as lime. In each case the hardness is reduced to from 3° to 5°.

The Maignen "Filtre Rapide" Co. are the makers of a plant which softens and filters the water automatically. By means of a small motor worked by the flow of the water to be softened, the proper amount of "Anti-calcaire" is added, and mixture takes place in a small tank. From this the water flows to another tank, where most of the sediment is deposited. Finally it traverses one of their rapid filters and reaches the storage tank in a completely

TABLE IX.

Number	1	2	3	4	5	6	7	8	9
	Grains per Gallon.								
Calcium Carbonate	8·74	13·15	16·39	10·99	9·19	2·06	9·41	8·34	1·39
Magnesium Carbonate	2·78	·33	·31	2·76	1·40	·94	1·00	2·82	1·78
Calcium Sulphate	3·26	...	4·30	2·99	12·17	47·34	22·91	40·61	54·14
Magnesium Sulphate	..	1·96	1·28	12·41	7·05	5·70	15·90	22·25	22·46
Magnesium Nitrate	..	...	...	..	13·69	...	11·50	...	...
Magnesium Chloride	...	...	...	...	·64	...	2·08	...	...
Total Solids	19·37	19·15	25·75	53·70	51·06	73·41	68·75	83·86	114·37
Total Lime (CaO)	6·24	7·36	10·95	7·39	10·16	20·64	14·70	21·39	23·07
Total Magnesia (MgO)	1·33	·81	·58	5·48	7·02	2·36	9·82	8·81	8·38
Total Hardness (= *Calcium Carbonate equivalent to Total Lime and Magnesia*)	**14·5**	**15·16**	**20·99**	**26·77**	**35·53**	**42·7**	**50·57**	**60·02**	**61·95**
Cost of Chemicals required for softening 1,000 gallons	¾d.	½d.	1d.	2d.	3½d.	4¾d.	5d.	6d.	7d.

Note.—The above estimates of cost are based upon the following prices, *viz.*:—
Quicklime . . . . at £1 0s. 0d. per ton. | 58 per cent. Soda Ash . . at £6 17s. 6d. per ton.

clarified condition. This is one of the processes which can be used on the small scale, for private houses, etc.

Although certain of the processes described would appear to require very little personal attention, according to the statements of the inventors, yet, if uniformly satisfactory results are to be obtained, there must be constant supervision. The treated water must be repeatedly examined to ascertain that neither too little nor too much of the lime or other chemicals is being added. If too little, the water will not be properly softened, and if too much, the water will be rendered alkaline, and the magnesia will not be removed. When the amount of lime added is a little less than the theoretical quantity required to precipitate wholly the lime and magnesia salts, the two carbonates separate in a form which settles well, and the softened water filters readily. When the full theoretical amount is used, or a slight excess, the carbonates deposit slowly, and in a form which rapidly clogs the filters. Even after passing the filter, more magnesia continues to separate for from twelve to twenty-four hours. When spring or deep-well waters are being softened, the best proportions of lime water and spring or well water having been once determined, it only remains to examine the water occasionally to see that these proportions are being maintained, and that the lime water is uniform in strength. If the lime water be not saturated with lime it will be too weak, whereas, if by undue agitation it is not only saturated, but contains lime in suspension, it will be too strong. With river waters the case is often different. The composition may vary considerably with the season, and, if a tidal river, with the state of the tide, and skilled examinations must be frequently performed to ascertain the exact proportion of chemicals to be added.

The Rivers Pollution Commissioners state that at Canterbury, Caterham, and Tring, the water is reduced 20° in hardness by Clark's process, at a cost of only 27s. per

1,000,000 gallons for lime and labour. This may be taken as a fair estimate of the cost for lime and labour of softening an average sample of such hard waters as are being used for town supplies. Assuming that the interest of capital expended in plant, buildings, land, etc., increases the cost to 1d. per 1,000 gallons, or £4 3s. 4d. per 1,000,000, and that the hardness to be reduced is only 16°, the following may be taken as a low estimate of the saving effected by the softening of a town water supply—

Cost of softening 1,000,000 gallons	£4	3	4
Suppose $\frac{1}{10}$ only is used for washing purposes (domestic and laundry), and that half of this is softened with the cheapest soda, and the remainder with soap, the cost would be, very approximately	£60	0	0
Suppose $\frac{1}{10}$ be used in steam boilers, that steam coal costs 13s. per ton, and that 25 per cent. more fuel be used on account of incrustation, the cost of additional coal is	9	2	0
Total	£69	2	0

This represents a saving of nearly £65 per 1,000,000 gallons, or of £23,000 a year to a town of 30,000 population. A town of one-third the size would save £7,000. Even in very small towns the saving would be enormous. This estimate is very much below those usually given by makers of softening apparatus, and in many cases the cost of softening is said to be less than that given above, and a larger proportion of water may be used for washing purposes. They forget, however, that all the water used for washing purposes is not completely softened. When used for personal ablution only the very small quantity taken up on the hands is completely softened, as the water after use is found to be only 1 to 2 degrees softer than before. The saving in the wear and tear of boilers, of culinary utensils, and the saving in the consumption of tea, are also items

which have not been taken into account in the above estimate, yet which can be made to show a very considerable pecuniary balance in favour of softened water. Under the most adverse circumstances, where the water contains both lime and magnesia salts, and is "permanently" hard, requiring the use of soda as well as lime for softening, and large tanks and filter beds for ensuring complete clarification, the cost could not exceed 1s. per 1,000 gallons, and the saving effected would be actually greater than in the towns where the cost was only 1d., since the waste of soda, soap, fuel, etc., which would be prevented, would be so much greater in proportion.

The particular method of softening best adapted in any given case depends upon many circumstances, such as the character of the water to be softened, the purpose for which it is chiefly required, the amount of available space, the available motive power, the amount of water required, and whether for constant or occasional use. The cheapest plant, which, with the use of the cheapest chemicals, and the least expenditure in labour, will produce the desired result, will naturally be selected, and this can only be decided upon when all the above factors have been duly considered. Under suitable conditions all are capable of giving excellent results.

During the process of softening, the bacteria contained in the water suffer a considerable decrease in number. Apparently these organisms become entangled in the precipitate formed, and settle therewith to the bottom of the tanks. Professor P. Frankland found that by agitating water with powdered chalk, the treated water after subsidence only contained about 3 per cent. of the organisms originally present. A carefully-filtered softened water, therefore, ought to be practically sterile. With waters of a high degree of purity, the filtration necessary after softening would be merely to remove suspended particles of carbonates; but where river water, known to be sewage

hand, where the supply is abundant and easy of access, a very large proportion is often wasted, and 100 gallons or more per person per day may pass from the mains into the sewers.

The purposes for which water is required may be summarised as follows—(*a*) For drinking, either as water or made into such beverages as tea, coffee, and cocoa, and for cooking purposes; (*b*) for personal ablution, including baths; (*c*) for household washing, including cleansing and swilling of floors, yards, etc.; (*d*) for use in water-closets; (*e*) for the supply of horses, cattle, and washing of carriages; (*f*) for watering plants and gardens in the dry season; (*g*) for municipal purposes, cleansing streets, flushing sewers, extinguishing fires, etc.; and (*h*) for manufacturing and trade purposes. Where for municipal and manufacturing purposes, water can be more cheaply obtained from wells, streams, or other sources, obviously the public supply of pure water needs not be nearly so large as in towns where such sources are not available. Where subsoil water can readily be obtained from shallow wells, it may be utilised for many of the above purposes, especially for the stable and garden, and the demand upon the public supply be further curtailed. The amount of water required for each of the above purposes has been variously estimated. Professor Rankine, in his work on *Civil Engineering*, states as his opinion that 10 gallons per head should be allowed for domestic purposes, 10 gallons for municipal purposes, and 10 gallons for trade purposes in manufacturing towns. Most engineers, however, consider the estimate for municipal purposes to be too high, since in the majority of towns the amount used does not exceed 3 gallons per head. For trade purposes also Rankine's estimate is probably excessive, 7 gallons per head being a liberal allowance. Dr. Parkes * measured the water expended in

* Parkes' *Practical Hygiene*.

several cases; the following was the amount used by a man in the middle class, who may be taken as a fair type of a cleanly man belonging to a fairly clean household:—

	Gallons Daily per One Person.
Cooking	·75
Fluid as drink (water, tea, coffee)	·33
Ablution, including a daily sponge bath, which took 2½ to 3 gallons	5·0
Share of utensil and house washing	3·0
Share of clothes (laundry) washing, estimated	3·0
	12·0

The above may be taken as a liberal estimate for domestic requirements applicable for most communities. Where water-closets are introduced, 2 to 6 gallons, according to the mode of flushing, must be allowed; for the supply of horses and cattle and use in garden 2 to 5 gallons; for municipal purposes 0 to 10 gallons, and for manufacturing purposes 0 to 10 gallons. Where the water is not required for trade or municipal purposes, a supply of from 16 to 23 gallons per head will suffice; but where the water is also wanted for cleansing streets, flushing sewers, supplying factories, etc., as much as 40 gallons may have to be provided. Allowing 2 gallons for unavoidable waste, we may take 18 gallons as the minimum and 42 as the maximum supply required by any community.

These figures may be checked by the actual amounts used in various towns. The Rivers Pollution Commissioners, in their Sixth Report, in discussing the question whether a constant or intermittent supply be the more economical, give two tables—one of the amount of water supplied per house in each of the seventy-one towns with a constant supply, and the other of twenty-four towns each having an intermittent supply. The following is a brief summary of the tables referred to:—

	Constant Supply.	Intermittent Supply.
No. of towns using not more than 50 galls. per house	3	1
No. of towns using over 50 and not more than 75 galls. per house	13	4
No. of towns using over 75 and not more than 100 galls. per house	8	2
No. of towns using over 100 and not more than 150 galls. per house	20	9
No. of towns using over 150 and not more than 200 galls. per house	10	2
No. of towns using over 200 and not more than 300 galls. per house	12	4
No. of towns using over 300 and not more than 400 galls. per house	2	2
No. of towns using over 400 galls. per house	3	0

The mean daily supply per house in the seventy-one towns was 135 gallons, in the twenty-four towns 127 gallons. Taking five as the average number of persons per house, the mean daily supply under the constant system was 27 gallons, and under the intermittent system 25.4 gallons. In London, with an intermittent system of supply, the average per person was 40 gallons (204 per house).

The amount of water supplied per house under both systems varied enormously. With a constant supply Heywood and Middlesborough furnished the two extremes. At the former town, with 5,200 houses and 30 factories, only 20 gallons per house per day were consumed; at the latter, with 7,000 houses and 80 factories, the amount was 700 gallons, or thirty-five times as much. The quantity stated to be supplied to Heywood is probably erroneous, since the Heywood and Middleton Company is elsewhere mentioned as supplying 7,000 houses and 150 manufactories with 100 gallons per house daily. This latter amount is, however, only one-seventh that of the Middlesborough supply, and the difference is the more marked inasmuch as both places are supplied by private companies, and the latter in each instance are reported to have inspectors who

examine the taps and fittings to prevent waste. With an intermittent supply, Huddersfield, with its 8,500 houses and 600 factories, only used 49 gallons per house daily, whilst Berwick, with 1,150 houses and 7 factories, used 330 gallons per house. That these enormous differences depend more upon the amount wasted than upon the amount used for either domestic, municipal, or trade purposes is almost certain. The consideration of a few more modern statistics confirms this opinion.

In the following table the amount of water used daily per unit of population in a number of representative towns is given. Most of the figures are taken from recent reports of Medical Officers of Health or Water Companies.

Town.	Population.	Water Supplied per Head Daily.
Saffron Walden	6,108	11 gallons
Melrose	1,300	13 ,,
Bridlington	9,806	16 ,,
Halstead	6,100	17 ,,
Chepstow	3,387	15 to 16 ,,
East Ham	33,000	20 ,,
Atherstone	5,000	20 ,,
St. Austell	3,400	21 ,,
Chelmsford	11,079	23 ,,
Bristol	222,000	23 ,,
Bedford	28,023	25 ,,
Weston-super-Mare	15,869	26 ,,
Swansea	93,864	27 ,,
Barking	15,115	26 to 30 ,,
Nottingham	211,984	28½ ,,
Wolverhampton	82,620	29 ,,
Grantham	16,746	30 ,,
Yeovil	9,648	31 ,,
Walthamstow	49,400	36 ,,

The variations here, though not nearly so great as in the River Pollution Commissioners' table, are still very considerable. Having recently to make an examination of the Halstead supply, I verified the above figures. The supply

there is constant, and the water is used for flushing sewers, watering the streets, etc., as well as for flushing water-closets, and other domestic purposes. In this town a large proportion of the women is engaged during the week at the crape factories, and Saturday is the great washing-day. The amount used on a Saturday was as under:—

From 8 A.M. to 2 P.M.	9,800 gallons per hour
,, 2 P.M. to 4 P.M.	9,500 ,, ,,
,, 4 P.M. to 5 P.M.	6,000 ,, ,,

The average amount used on a week-day was 104,000 gallons, and on Sundays 84,000 gallons. Small as this amount appears, there is no doubt that a considerable portion was wasted, since many thousands of gallons passed from the service reservoir during the night, when little or none was being used.

At Wolverhampton the careful records kept at the Corporation Waterworks show that in 1868 "the domestic consumption per head of consumers, deducting for trade purposes, street watering, etc.," was 18 gallons. In 1892 it had increased to about 23 gallons. In the latter year the total amount supplied for all purposes was about 29 gallons per head daily.

At Newcastle the consumption per head, for all purposes, in 1863 was 28 gallons; in 1881 it had increased to 38½ gallons. "This," says Dr. Armstrong, the Medical Officer of Health, "shows an increase of 37 per cent. in the amount consumed for each person, due, no doubt, largely to improved habits of cleanliness among the people. Looking at the fact that baths and water-closets, which even then were considered as luxuries, are now regarded as necessities in almost every house of any pretensions to comfort, . . . it is not too much to assume that there will be a still further increase in the consumption per head." No doubt this in a measure is true, but it is at least probable that much of this increased consumption is really

increased waste, consequent upon the increased age of the mains and fittings. In London, by greater attention to the sources of waste, the net supply per head of population has in many cases been very considerably decreased. The following table * is interesting as showing the actual amount of water supplied daily by the London Companies and the wide difference in the supply per head.

Name of Company.	Net Supply Daily.	Population.	Net Supply per Head.
New River	32,640,976	1,159,260	28·16
East London	39,704,601	1,158,500	34·27
Chelsea	9,557,388	287,362	33·25
West Middlesex	15,419,907	577,235	26·71
Grand Junction	16,701,734	350,000	47·72
Lambeth	20,234,560	655,921	30·85
Southwark and Vauxhall .	24,373,348	841,989	28·94
Kent	12,530,891	460,524	27·21
	171,163,385	5,490,791	31·19

Of this quantity it is estimated that about 20 per cent., or between 6 and 7 gallons per head, is used for trade and municipal purposes. Whilst the West Middlesex Company supply only 27 gallons per head, the Grand Junction Company supply 48 gallons, and this the engineer of the latter company explained to be chiefly due to waste, since they found it cheaper to pump water than to supervise and control the waste.

The following table is taken from a paper by Mr. T. Duncanson, A.M.I.C.E., on "The Distribution of Water Supplies," read before the Liverpool Engineering Society, April, 1894.

* *Report of Royal Commission on Metropolitan Water Supply*, 1893.

Name of Company or Town.	Year.	Domestic Supply in Gallons per Head.	Trade and Public Supplies. Gallons per Head.	Total Gallons per Head.	Percentage of Supply. Given Constant.
Liverpool . .	1893	17·10	9·8	26·9	100
Bradford . .	1891	18 to 20	20·0	38 to 40	100
Manchester . .	1893	15·0	9·0	24·0	100
Birmingham . .	1893	17·0	8·75	25·75	100
Glasgow . . .	1893	36·0	16·0	52·0	100
St. Helens . .	1893	18 to 21	18 to 20	36 to 41	100
Swansea . .	1893	23·4	4·2	27·6	32

All waste is included in the amount set down for domestic supply.

The amount of water supplied per head per day in many cities in the United States is enormous. The following figures are taken from Vol. xxxix. of the *Engineering Record* (p. 322). New York in 1870 used 82 gallons per head per day, in 1899 the amount had risen to 119 gallons. In Boston, in 1895, 90 gallons were supplied and used as under:—

For municipal purposes	5	gallons
For trade purposes	30	,,
For domestic use	40	,,
Unavoidable (?) waste	15	,,
	90	,,

In Philadelphia (*Engineering Record*, vol. xxxix., p. 430) no less than 230 gallons are supplied, but it is stated that half to two-thirds is recklessly wasted. On the other hand, certain continental cities have a much more limited supply than London. In Berlin, for example, the daily supply is said to be only 20.56 gallons per head per day, 20 per cent. being used for municipal purposes and 80 per cent. for domestic purposes.

Waste of water arises from two distinct groups of causes —(*a*) those over which the consumer has no control, and (*b*)

those under the control of the consumer. As a rule the latter causes are responsible for the larger portion of the waste. Under (*a*) are included leakages from faulty mains and service pipes, and all other hidden defects, where the water escapes unperceived into drains and sewers or into the subsoil; under (*b*) the waste from defective house fittings, leaving taps open, etc. Such waste is also supplemented by an unnecessarily great consumption, due to the use of imperfect appliances, such as many forms of closet basin, and flushing tanks, the automatic flushing of urinals, and to the use of water for gardens, fountains, and similar purposes.

By the employment of a staff of inspectors the waste arising under (*b*) may be in a great measure controlled, but something more is required for the discovery and check of that arising under (*a*). By the use of water-waste meters or detectors the particular branch mains from which the water is escaping can be discovered, and by the aid of an instrument resembling a large stethoscope the faults can be localised. The "Deacon," "Tyler," "Kennedy," and "Ginman" waste detectors are those best known. These meters register automatically and continuously the rate at which the water is passing through the mains to which they are attached. It can thus be ascertained whether the draught has been excessive at any particular time, or whether this is constantly high. The number of houses supplied through each meter being known, it is easy to decide whether the amount of water which has passed is in excess of their requirements. If, after an examination of the fittings and rectification of visible defects, waste still continues, the mains and service pipes require attention. If the ear be applied to the service pipes near where they emerge from the ground, any escape of water from the pipe or main in the immediate neighbourhood can be heard, the more distinctly the nearer the defect. The ear can also be applied to the uncovered main for a similar purpose, but it

supply to 23 gallons without any restrictions being placed upon the consumers. At Shoreditch, with a population of 87,000, the introduction of waste detectors effected in the course of three years a diminution of waste and undue consumption amounting to 720,000,000 gallons per annum, or 23 gallons per head daily. Mr. Boulnois recommended the use of Deacon's meters at Exeter, and their introduction reduced the waste from 75 to 12 gallons per head per day.

In other parts of London, in Bradford and elsewhere, where waste detectors have been introduced, the expenditure of water has been reduced by from one-third to one-half.

A most instructive instance of what can be done by checking waste was given by Mr. Hawksley in evidence before the River Pollution Commission. He said that when "the city of Norwich Waterworks were transferred from a very old-fashioned company to a new one . . . the delivery amounted to 40 gallons per head per diem, and that amount of consumption exhausted all their pumping power. They obtained a very good manager, and, under my advice, they applied for an additional Act of Parliament to enable them to correct the fittings. . . . The bill was carried, and it was put into operation, and now and for many years past, although the constant supply has been unfailingly in use, the water is never shut off, and the consumption has descended to 15 gallons per head per diem, as compared with 40 previously." In many cases a check is placed upon waste by placing in the service pipe leading to the house cistern a disc with a small hole in it, which prevents more than a certain amount of water passing through in a day. This, however, is a most objectionable arrangement, and quite unnecessary, since better results are obtained by adopting regulations as to the strength, proportion, and quality of the fittings, and enforcing the regulations.

In America water meters are being largely used to prevent waste, and with great advantage. For example, in Milwaukee before meters were generally adopted the water used per tap was 1,781 gallons per day. Now, when the great majority of houses are furnished with meters, the amount used per tap is only 644 gallons.

In tropical climates, doubtless, the demand for water is greater, and probably even 30 gallons per head per day would be barely sufficient. In Bombay 40 gallons is supplied, and in Calcutta 35.4 gallons of filtered water and 8.9 gallons of unfiltered, total 44.3 gallons; but in many other cities the amount used falls far short of this. In Madras, for instance, only about 18 gallons is supplied; but this is very probably far too little for all the requirements of the population.

The amount of water required by various animals naturally varies, chiefly with the size. Cavalry horses are allowed 8 gallons, and artillery horses 10 gallons per day. Elephants require at least 25 gallons, camels 10 gallons, and oxen 6 gallons per head daily.

By a careful study of the requirements of any community the amount of water which must be supplied daily may be estimated with a fair approach to accuracy; but whilst every care is taken to avoid waste, it must be remembered that this cannot be entirely prevented, and that it is far wiser to provide a supply in excess of the requirements, so as to be prepared for contingencies, and for a possible increase in the demand, from growth of population and other causes.

The amount of water used per week throughout the year does not vary greatly, but, as a rule, more water passes through the mains in summer than in winter. In Liverpool, during 1893,* the maximum consumption took place in the week ending 8th July, and was about 15 per cent. above the average, and the minimum during March,

* Duncanson, *loc. cit.*

November, and December, and was about 9 per cent. below the average. (*Vide* Chapter XXI.)

In small towns and rural districts where a large number of houses have gardens attached, the summer consumption of water is often greatly in excess of that used in winter. The most stringently enforced regulations often fail to prevent water being used in excess for gardening purposes during seasons of drought, and such misuse of the water by persons living in the lower portions of a district may deprive those residing upon higher ground of the supply to which they have an equal right.

CHAPTER XVII.

SELECTION OF SOURCES OF WATER SUPPLY AND AMOUNT AVAILABLE FROM DIFFERENT SOURCES.

WHERE there is only one source of water available there is no question of selection, since there is no choice. Such instances, however, are comparatively rare: usually there are more sources than one from which water can be obtained; and in deciding upon one or another many points have to be considered. A water seriously contaminated with sewage or intermittently liable to such contamination, water containing mineral matter in excessive quantity or of deleterious quality, and water with any marked odour or colour, would naturally be at once rejected. *Cæteris paribus*, the water of greatest hygienic purity and best adapted for manufacturing purposes would be selected. Where the available quantity or economy in utilisation, or both, are in favour of a water from a certain source, the importance of these factors must not be allowed to outweigh those of purity and freedom from risk. As the characteristics of good drinking waters and the dangers attendant upon the use of polluted waters have already been discussed, it is not necessary to do more than refer to them here, special attention being directed to the sections dealing with river water, the self-purification of rivers, and the discussion of the risks involved in the utilisation of river waters admittedly polluted, even when the intake is many miles below the source of pollution and the filtration is conducted according to most modern methods. Where

towns of any magnitude are concerned, the subject is so important that the services of experts—engineering, medical, and chemical—would naturally be enlisted; and by these all the advantages and disadvantages of the different available sources would be carefully considered, and the decision arrived at would be based upon the facts recorded and the opinions expressed in their reports. The nature of much of this evidence may be inferred from the sections treating of the quantity and quality of water obtainable from various sources, since the information there given is of general application. The estimates of cost of collecting, storing, and distributing will vary in each individual case, and certain points bearing upon these questions will now be briefly considered.

In the first instance, however, it will be better to consider the simplest case—that of providing a supply of water for a single house or small group of houses. In this, as in undertakings of greater magnitude, some knowledge of the geology of the district is in most cases absolutely necessary. Without this the search for underground water is mere groping in the dark, which may or may not be successful. Where a spring, however, is available, doubtless this will be at once selected, especially if it arises at such an elevation as to be capable of supplying the house or houses by gravitation. In examining any district for the discovery of springs, the sides of all streams should be carefully examined, and all tributary rivulets should be followed up to their respective sources. If the flow of the stream appears to be considerably augmented at any point, it is probably due to the influx of water from a spring, which may permit of being tapped above the point of discharge. In this case the construction of a reservoir large enough to hold at least a day's supply and the laying of a service main is all that is required. One great mistake is, however, frequently made in this simple arrangement. The pipe is rarely of sufficient size, and sometimes

is not of suitable material. Galvanised iron pipe of 1 inch or even less diameter is often employed to convey water considerable distances. If the water contains little or no carbonate of lime, the zinc will almost certainly be dissolved and contaminate the water. The pipe then becomes coated with a deposit of iron oxide, which tends continually to increase, and ultimately the calibre of the tube becomes too small to convey the required quantity of water. I have known many cases in which such pipes have had to be taken up and larger ones substituted. Cast-iron pipes coated inside with Angus Smith's protective varnish should be used, and the diameter should never be less than 2 inches. Where water is required for fire-extinguishing purposes also, the diameter of the pipe must be considerably greater, and the reservoir must be much larger. The size of main required under different circumstances will be discussed when the "distribution of water" is being considered.

The character of the water yielded by springs from different geological formations has been discussed in Chapter V., and the variable yield from certain springs have also been referred to. Before attempting to utilise any spring as a source of water supply evidence should be obtained proving that even after periods of continued drought the yield is sufficient for the purposes required. Many springs which flow freely in the late winter, spring, and summer fail completely in the autumn, or at least yield a greatly diminished supply. The evidence of people who may have used the spring or observed the flow for many years will have some weight, but must not be too implicitly relied upon. The flow should be gauged from time to time and the effect of the rainfall ascertained, bearing in mind that the flow may not be affected by even long continued heavy rains until after the lapse of some months, and that the effect of a long continued drought may not be observed until long after it has passed away.

The less variable the flow, the more likely is it to be constant; the longer the interval between a heavy rainfall or a drought and the production of any effect upon the flow, the less likely is such an effect to be serious. As a rule land springs flow most copiously in February and March, and are lowest in October and November. The gaugings therefore in the autumn and early winter are the most important, since the minimum flow is the information required. If the character of the previous summer be also taken into account reliable inferences may be drawn from the results. Small springs may be gauged by ascertaining the number of seconds required to fill a bucket of known capacity, or better still by employing a large vessel, such as a tank or tub. Or the water may be caused to flow along an open channel, or trough, when the cross section and velocity of the water in the trough can be ascertained, and an approximate estimate of the flow easily calculated. Larger springs may be gauged by damming up the water and allowing it to discharge over a board from which a rectangular notch has been cut. The notch should be two or more inches wide and the edges chamfered. The principle involved is the same as that already described for gauging streams, and the height of the horizontal surface of the water behind the dam above the lip of the notch being measured, the flow can be ascertained from the formula there given. The following table gives the discharge in gallons per minute and per day over a notch-board for each inch of width, and for varying differences of level. The quantity given in the table, multiplied by the width of the notch used, in inches, will give the yield of the spring at the time of gauging. With notches exceeding 3 inches in width the results may be relied upon; with narrower notches they are not quite so reliable. Moreover, where the flow is so small that a notch of less than 3 inches is required, the simpler plan of actual measurement is much preferable.

Depth.	Flow per Minute.	Flow per Day.	Depth.	Flow per Minute.	Flow per Day.
$\frac{1}{4}$	·31	446	$2\frac{1}{2}$	9·8	14,112
$\frac{1}{2}$	·88	1,267	3	12·9	18,576
$\frac{3}{4}$	1·62	2,333	$3\frac{1}{2}$	16·3	23,472
1	2·50	3,800	4	19·9	28,656
$1\frac{1}{4}$	3·48	5,011	$4\frac{1}{2}$	23·8	34,272
$1\frac{1}{2}$	4·57	6,580	5	27·8	40,032
$1\frac{3}{4}$	5·76	8,294	$5\frac{1}{2}$	32·1	46,224
2	7·0	10,080	6	36·6	52,704

It is a noteworthy fact that although springs are not abundant on the chalk formation, yet some of the largest springs in the country arise in the chalk.

Where a spring is not available attention will probably be next directed to the subsoil as a convenient source of supply, in which case a slight knowledge of the geology of the district may be invaluable. The points to which attention must be directed have been referred to in the chapter treating of "subsoil water." The character of the strata within reach being known, and the directions in which they dip and the depth and position of the nearest wells having been ascertained, the presence or absence of water at any particular spot may usually be predicted, as well as the depth at which it will be reached. Where the subsoil is permeable and the water held up by an impervious stratum beneath, depressions in the ground, and spots upon which herbage is most abundant or appears greenest, will often indicate where the water most nearly approaches the surface. At sunrise and sunset films of vapour (mist) usually arise first over the damper portions of an area, and continue of greater density there than elsewhere. "On a dry sandy plain, morning mists or swarms of insects are said sometimes to mark water below" (Parkes). Near streams and near the coast water is generally found at a slight depth. This is the subsoil water flowing towards its natural outlet. Near the sea, however, the

wells may and often do yield brackish water. Even when some considerable distance from the coast, the continued maintenance of a low level in the well may result in the water becoming saline. During a recent exceptionally dry season, the water in a well supplying a town on the coast was markedly affected, although the well was $1\frac{1}{2}$ miles from the shore. The chlorine, which is normally about 3 grains per gallon, gradually increased, until a maximum of 18 was reached. In hilly districts water is most likely to be found in the lowest portions of the valleys. Where the water-bearing stratum is covered with an impervious one, the search for water is much more difficult, but a careful study of the local geology, to ascertain the dip of the various strata and the thickness of those lying above the water-bearing rock, will usually lead to reliable inferences being drawn. This is not invariably the case, however. Thus in Essex a considerable portion of the London clay is capped with drifts of sand and gravel and boulder clay. The sand and gravel lying between the London and the boulder clay varies in thickness, and in some places is entirely absent, and it is often impossible to predict whether, by sinking at any particular spot, water will be found or not. This uncertainty has led to "water-finders" being employed, and as there is a pretty general belief in the powers of the hazel-twig in the district, it would appear as if the finders were usually successful. I have paid some attention to this subject lately, and find that from the manner in which the hazel-twig is held, by imperceptible muscular movements it can be made to rotate between the hands. I have seen the water-finder walk over places where water existed in abundance without the twig indicating its proximity. In localities which have been traversed by the finder, I have usually found that there was no difficulty in indicating where water could be obtained without the use of a hazel-twig. In one instance the hazel-twig gave strong indications of the presence of

water at a point at which I was certain there could be no water within 300 feet, since the soil was of clay; and in that particular district it was known to be 300 feet in thickness. The owner of the land, however, had every confidence in the water-finder and proceeded to dig a well. When he had penetrated the clay to a depth of about 100 feet and found no indication of water, his confidence vanished, and the work was abandoned. A gentleman with whom I am acquainted contends that the hazel-twig in his hands gives reliable information. He believes that the presence of the water affects him personally, and the twig through him. Twigs of other trees do not answer, since they do not possess the necessary elasticity, and cannot be made to rotate nearly so readily as the hazel. He has certainly, recently, been able to indicate the presence of water in unsuspected places, and as in his case there can be no suspicion of intentional deception, the result must either be due to accident plus unconscious cerebration, or to some, at present, inexplicable influence of water upon himself or the twig. A recent success was recounted in a letter which he addressed to me on 19th May, 1894. He says, "General ——— asked me if I would give my opinion upon the practicability of finding water in a field facing his house. I went over and marked out two spots, and at each of these places digging was commenced, and at less than 10 feet from the surface water was found. . . . I should add that some time since an engineer made experiments upon the same ground with boring apparatus, but gave it as his opinion that within the area no water was available." According to the geological drift map, the parish in which General ——— resides is partly on London clay, partly on gravel, and partly on boulder clay capping the gravel, and it would seem an easy matter to indicate almost the exact limits of the area in which water could be found. In justice to my friend, however, I must add that he knew nothing of the geology of the district.

Certain points requiring attention in selecting the site for a well are referred to in Chapter IV., and the possible effect of the pollution of the drainage area of the well, and the dimensions of this area, are discussed in Chapter XI. Before works of any magnitude are undertaken for utilising subsoil water, the area of the collecting surface should be ascertained, its configuration, etc., considered, and the depth of the ground water and the extent of its fluctuations determined. The less the fluctuation the more likely is the supply to be permanent, and the less the liability to contamination. Rapid fluctuations usually indicate variation in quality, as well as quantity, of the available water. Where limited amounts only are required, and the possibility of finding water or of determining the quantity available cannot be inferred, from the absence of similar wells in the vicinity, trial borings or sinkings must be made. The character of the strata penetrated must be noticed, and the boring continued until water is found or an impervious stratum reached. Into the latter it is unnecessary to bore unless it is believed to be of but slight thickness, and the water above it is not sufficiently abundant. Thin beds of clay are sometimes found in thick gravel drifts, and they hold up a certain amount of water, which is obtainable by pumping. When the clay is penetrated, the gravel beneath may not be fully charged with water, in which case that found above will run through and be lost. This is the explanation of the mysterious disappearance of water from certain wells which have been deepened to increase the supply or the storage capacity. Instead of the supply being increased, the limited amount previously obtainable has been lost, and the work has either been abandoned or an attempt made to reach the water, if any, held in the lower pervious layer. Where no impervious stratum is penetrated, the water when reached will not begin to rise in the bore hole, or

only to a very slight extent, since it is not under pressure. In deep wells, which will be considered later, as soon as the water-bearing rocks are reached, the water begins to rise, more or less rapidly, and may even overflow at the surface. In sinking shallow wells the trial bore must be continued until the depth of water is judged sufficient. By pumping the water out of the bore hole and noting the time required for it to again ascend to its former level, the abundance or otherwise of the supply may be judged,—the more rapid the rise the greater the available amount of water. The yield of a well is often gauged by the length of time required for it to fill to its normal level after being pumped dry. The depth of water and the diameter of the well being also known, the yield is easily calculated. The result so obtained is always too low, since the rapidity with which the water enters varies with the square root of the head, and the head varies with the difference between the level of the subsoil water and the level of the water surface in the well. A more accurate result therefore is obtainable by starting with the water at a conveniently low level (say at half the usual depth), and ascertaining the amount which must be pumped in a given time in order to maintain it at this level. Such experiments only indicate the amount available at that particular time, but if made after a long drought, the result will probably indicate the minimum yield of the well.

Many attempts have been made to devise formulæ for calculating the yield of water from wells and galleries (*vide* Frühling's *Handbuch der Ingenieurwissenschafen*). Certain of these have been discussed by Fuertes (*Engineering Record*, vol. xxxix., p. 28). The following is given for calculating the yield from a well sunk in a sandy or gravelly subsoil:—

$$Q = 3{\cdot}142X\,(H^2 - h^2) \div \text{natural log.}\,(2R \div d),$$

where

Q = the yield in gallons per second.
H = depth of water in well, at rest, in feet.
R = radius of zone of depression.
h = depth after pumping in feet.
d = diameter in feet.
X = PV, where P = the percentage of void in the sand or gravel (usually 30 to 40 per cent.) and V = the coefficient of velocity of flow of water in the gravel = about ·29 times the square of the effective size of the sand or gravel in millimetres.

Obviously there are so many factors which cannot be determined with certainty that such a formula can have little value.

Where the limited space available necessitates the well being sunk near drains, sewers, cesspools, or other similar possible sources of pollution, not only should every care be taken in the construction of the well, drains, sewers etc., to avoid contamination of the water supply, but the risk should be reduced to a minimum by sinking the well in such position that the flow of the subsoil water shall be from the well towards the drains, and not from the drains towards the well. In villages and on farms the ground water is usually so polluted as not to afford a safe supply, however carefully constructed the well. Good water can, in some cases, be obtained at a little distance away in the direction of the higher ground-water level. This distance will vary in different places according to the porosity of the subsoil, slope of the ground water, and amount of water to be pumped. Where water is only pumped in small quantities at a time, the influence of the pumping will extend but a short distance from the well; but where a supply tank or water butt has to be filled from time to time, the level of the water in the well may be considerably depressed and the drainage area be greatly extended (*vide* Chap. XVIII.). According to the permeability of the subsoil, the area capable of being drained

by the well will vary in diameter from 15 to 160 times the normal depth of water in the well. In a loamy soil a distance of 20 times this depth may be sufficient for safety; in very coarse gravel the distance should be 150 times the depth. Where the slope of the ground water is steep there might be safety within these limits, as the influence of the pumping would not be nearly so marked at the side of lower water-level; but as the plane of saturation is usually nearly horizontal it is best to err on the side of safety and regard it always as such. Whether the water should be obtained by sinking an ordinary well or by driving a tube well, may be decided after considering the advantages and disadvantages and relative cost of the different kinds of well as described in Chapter XX., on "Well Construction."

Where springs are not available, and water is not obtainable from the subsoil, the possibility of obtaining a supply from a deep well may be considered. As this is a somewhat serious undertaking, probably attention had better be directed in the next place to the supply which can be obtained directly from the rainfall. It is agreed that about half the rain which falls upon the roof or similar impervious surface during the whole year can be collected. The other half is lost by evaporation and by waste from the separators and filters. Why should not this rain water be stored and utilised? Even where water is obtainable for drinking purposes from springs or wells, it may be so hard or so limited in amount that it is desirable to collect the rain water for use in the laundry and for personal ablution. A fair-sized mansion has often a roof area sufficiently large to collect enough rain water for drinking, cooking, and general domestic purposes. Assuming the area covered by the roof to be $\frac{1}{4}$ of an acre (1,210 sq. yards), and the minimum rainfall 20 inches, then 10 inches of this may be collected. As a fall of 1 inch upon an acre represents 22,620 gallons, 10 inches upon $\frac{1}{4}$ of an acre represents

56,550 gallons for the year, or 155 gallons per day, a supply which would suffice for ten persons, allowing 15 gallons per head, or for 15 persons at 10 gallons per head. In most parts of the country the minimum rainfall reaches 25 inches, therefore admitting of a more abundant supply. Where the roof surface is not sufficiently large it has been proposed to prepare a plot of ground for the purpose. The best method of collecting, storing, and utilising rain water was discussed when treating of rain water as a source of supply (Chap. II.), and that section must be consulted for further details.

Where larger quantities of water are required, as for villages and towns, it may be derived from the rainfall on natural gathering grounds, from the subsoil, from springs, from deep wells, or from streams. Water collected in hilly districts from uncultivated surfaces, forms, as we have already seen, one of the best and purest supplies obtainable. A large number of towns in this country are supplied from such sources. Unfortunately in several instances the amount of water obtainable in the area of the watersheds has been over-estimated the result being that in exceptionally dry seasons something like a water famine has occurred. The approximate determination of the amount of water which can be collected from the surface over a given area is one of the most difficult problems in water engineering, since it depends upon so many factors, some of which (the meteorological conditions) are so variable as almost to defy our efforts to predicate their possibilities. Upon these meteorological conditions, so variable in themselves, depend in a very great measure two other factors—the loss by evaporation and by percolation. The only factors which are uninfluenced by the weather are the area, configuration, and character of the collecting surface. The 6-inch ordnance maps give the contour lines or lines of equal altitude drawn at every 25 feet. The ridge or watershed lines are also marked, and

from these the ground slopes downwards on both sides. These lines are continuous, save on the side which forms the natural outlet of the water collected in the enclosed area of gathering ground, technically known as a "drainage area" or "catchment basin." In one such catchment basin, branching ridge lines may form two or more secondary drainage areas. The area from which the water is to be collected may either be ascertained by actual measurement or be calculated from an ordnance map. The configuration, character of the surface and of the subsoil, and nature and amount of vegetation, require careful examination, since they influence greatly not only the amount of rainfall which percolates, but also the amount of loss by evaporation. A portion of the water which penetrates the ground in one part of the area may reappear in another part as springs, or it may be that the springs fed by the ground water lie entirely outside the boundary of the watershed, in which case a further portion of the rainfall escapes collection.

Where the hills are steepest, the rocks hardest, barest, and most impermeable, the loss both from evaporation and percolation will be smallest. The more permeable the subsoil, the more abundant the vegetation and the less steep the slopes, the greater will be the loss by evaporation and absorption. Where the soil is peaty, where moss abounds and bogs are extensive, much water is retained; it neither runs off the surface nor percolates into the subsoil, but is slowly lost again by evaporation. The loss by percolation is greatest where the subsoil is very porous—as when it consists of sand and gravel—and when the outlet for the ground water is outside the collecting area. However, as a rule, the localities selected as gathering grounds for water supplies have but a small proportion of their areas covered with any depth of permeable subsoil, since such ground is objectionable, not only because of the amount of water which it permits to percolate, but because,

in this country at least, it would be cultivated or used for pasturing cattle, and would therefore tend to pollute the water. The amount of water which may be lost by percolation has been referred to in Chapter IV. Both this and the loss by evaporation are affected greatly by the character of the rainfall. If the rain descends in frequent slight showers, the whole may be lost; whereas if the same amount falls in a few heavy downpours, a large proportion will run off the surface and may be collected. In the hilly districts selected as gathering grounds the rainfall is not only usually more abundant than in the plains, but it descends in sharper, heavier showers. As the water collected from any given area would otherwise have found its way into some stream or formed the natural source of such stream, the problem of ascertaining the amount of water which can be collected is frequently the same as that of determining the amount of water available from a stream. These we have already considered in Chapter VII., under the heads of (*a*) area of watershed, (*b*) the topography and geological character of the ground, (*c*) the average rainfall and the rainfall during a consecutive series of dry years, (*d*) the seasonal distribution of the rainfall, (*e*) the amount of water which must be supplied for "compensation" purposes, and (*f*) the facilities for obtaining storage. Based upon this knowledge engineers have devised formulæ for estimating the probable daily yield of a catchment area. Dr. Pole's formula is—

$$Q = 62A\left(\tfrac{4}{5}\,Rm - E\right).$$

In this equation Rm represents the average rainfall of a long series of years, and $\frac{4}{5}$ Rm the estimated average of the three driest consecutive years. E = the loss of rainfall by evaporation, percolation, and unavoidable waste; and A = the area of the gathering ground in acres. As 1 inch of rainfall upon 1 acre represents 22,620 gallons of water,

the average amount of water which can be collected yearly during the three driest consecutive years would be

$$22{,}620A \times (\tfrac{4}{5}\,Rm - E).$$

Since 22,620 divided by 365 is approximately 62, Pole's formula gives the mean daily yield of water from the catchment area. The importance of the factor E is evident, and it is to the fact that this has been occasionally under-estimated that the scarcity of water in certain towns during long-continued periods of low rainfall is chiefly attributable. In some cases, however, the fault has been due to the reservoirs not having been sufficiently capacious to allow of the accumulation of an ample reserve to tide over such periods of drought. Under any circumstances the most capacious reservoirs may become filled, and rain continue to descend and pass down the bye-wash and be wasted. This unavoidable loss Mr. Hawksley estimates at one-sixth of the rainfall. The loss by evaporation and percolation—which, as we have seen, depends upon so many factors—is variously estimated by engineers who have studied this subject. Mr. Hawksley found at Sheffield that it was nearly 15 inches, "although the ground is very elevated, ascending to 1,500 or 1,600 feet; but it lies rather with a southern aspect, and the ground is mossy, and a good deal of water is held superficially, and of course is re-evaporated." In this country the loss by evaporation and percolation is given by the following authorities as under:—

Mr. T. Hawkesley,	11 to 18 ins.	Average 14 ins.
Dr. Pole,	12 to 18 ins.	
Mr. Humber,	9 to 19 ins.	Average 13 to 14 ins.
Mr. Bateman,	9 to 16 ins.	

Over most favourable areas, therefore, the loss may not exceed 9 inches, whereas over the most unfavourable ones which are likely to be selected as gathering grounds it may be as high as 19 inches. The value of E in Dr. Pole's for-

mula, therefore, will vary from $\frac{Rm}{6} + 9$, to $\frac{Rm}{6} + 19$, $\frac{Rm}{6}$ being the unavoidable waste.

The amount of storage necessary to render the required amount of water available during the longest drought varies considerably in different places. Where the rainfall is heaviest the storage necessary is least, and *vice versâ*. Over the western half of this country, and in the more mountainous districts, 120 days' storage has been found sufficient, but in the eastern counties a storage for 300 days might even be required. In such districts, however, surface water is very rarely used for town supplies. There are few suitable collecting areas, and the rainfall is too low and too varied in its seasonal distribution to justify any attempt to obtain water from such sources. In those parts of England in which surface water can be rendered available a drought extending over 120 days, or a succession of droughts corresponding to that period, must be so rare as to be phenomenal. In works of such vast importance all errors must be on the safe side; it is wisest, therefore, to make provision for 150 days' drought even in districts with heavy rainfalls, and in less favoured districts to provide for the storage of 200 days' supply. This appears to be the general opinion of the most eminent engineers. It is impossible to give any precise rules as to the relation of the rainfall to the amount of storage. Mr. Hawksley's well-known formula gives results which confirm the opinion expressed by Dr. Pole, quoted below. Let D = the number of days' storage necessary, and F = the mean annual rainfall of a long series of years, then according to Hawksley

$$D = 1{,}000 \div \sqrt{F}.$$

With a rainfall of 25 inches this formula gives 200 as the number of days' storage required; with 49 inches 143 days would suffice. Dr. Pole says "the general judgment of

experienced practitioners appears to be that for large rainfalls a storage of 150 days or even less will suffice, but in drier districts it may be necessary to go as high as 200 days; . . . and this is a provision which may reasonably be borne." The extent to which the character of rain water can be affected by the surfaces from which it is collected was referred to in Chapter III.

Subsoil water is not utilised nearly to the same extent for supplying towns as surface and river water, whilst rural communities still continue to be supplied chiefly from this source. The factors upon which the amount of water available in the subsoil can be estimated have already been considered. A single well may yield sufficient water for a large village, or if the subsoil be chalk or sandstone and admit of headings being driven in various directions from the bottom of the well, one well may even supply a town of moderate size. Where, however, two or more wells are required, necessitating a corresponding number of pumping stations, a considerably increased expenditure is incurred. A village may sometimes be supplied from a single well in a patch of gravel, but usually such drifts are not sufficiently extensive or thick to yield a constant supply of any magnitude.

The chalk formation in most cases contains a large store of excellent water, but a single well, even with headings, rarely yields enough water for a large town. The drainage area of chalk wells cannot be estimated, since the water exists chiefly in and travels through the fissures, and but very slightly, if at all, through the chalk itself. It is evident therefore that the freedom with which water percolates through a chalk subsoil will depend upon the abundance and size of these fissures. If the fissures are numerous and large the drainage area may be very considerable. The well referred to on page 324 as being affected by the sea, $1\frac{1}{2}$ miles away, is sunk in the chalk. Cases are also recorded in which impurities have

been found to enter a well after travelling a very considerable distance through such fissures. As an example of the amount of water obtainable from wells in the chalk, the case of Croydon may be cited. The old waterworks are close to the town, and comprise four wells sunk in the chalk within a space of 100 feet square. The level of the water in the wells is not more than 25 feet from the surface, and the fissures yielding the chief portion of the supply are about 25 feet lower. Over 3,000,000 gallons per day have been pumped from them. To meet the increasing demands of the town a new well was opened in 1888. This is sunk 200 feet, all in the chalk, and is 10 feet in diameter. Water was first found at 87 feet. At 142 feet from the surface and below headings have been driven. The yield from the well was 130,000 gallons a day, but the first fissure cut by a heading increased the daily yield to 600,000 gallons, and when the yield reached 2,500,000 gallons a day the work in the well had to cease through the inability of the two 24-inch pumps to keep the water down. The total length of the headings is 813 yards, and they are generally 6 feet high and 4½ feet wide. The storage capacity of these and the lower part of the well is about half a million gallons (*Borough Engineer's Report*, 1890). A well such as that just described is usually spoken of as a "deep" well, although sunk entirely in one pervious stratum. The chalk, new red sandstone, oolite, and greensand contain vast stores of water of excellent quality accessible over very large areas to the well-sinker or borer, but it must not be forgotten that there is a little uncertainty in searching for water at such depths. The most experienced geologists are sometimes at fault. The variations in thickness of the water-bearing stratum and of the strata resting upon it, the possibility of hitherto unsuspected faults existing, must all be borne in mind. The water, also, when found, may be quite unsuitable for domestic purposes. Thus in Essex many of the borings

piercing the London clay yield a water containing so much sulphate of magnesia as to be aperient in property, whilst others have yielded a water so brackish as to be useless. The presence of beds of gypsum and of rock salt in the new red sandstone must not be forgotten, the former rendering the water excesively hard and the latter salty. At Rugby a well sunk 1,200 feet yielded only brackish water, and at Middlesborough a well which was sunk for obtaining a pure water yielded so strong a brine that salt is extracted from it. At Wickham Bishops, Essex, a boring was sunk to a depth of about 1,000 feet without water being found, yet everything had indicated that an abundance of water would be reached at a depth of about 500 feet. The section showed that there existed a previously unknown and unsuspected fault crumpling the London clay back upon itself, so that this stratum had to be twice pierced. When the second layer had been penetrated and no water discovered the work was abandoned. In other places the fall in the water-level from the heavy continued pumping indicates that a time may come when such supplies will fail, and unless the site of the well has been carefully chosen, others may be sunk in such positions as seriously to affect the supply.

The amount of water obtainable from a deep well in any particular locality is difficult to predict, but a consideration of the conditions bearing thereupon, referred to in Chapter VI., will assist us in arriving at fairly safe conclusions. The information contained in the next chapter, gathered from experienced well-sinkers, engineers, geologists, and others, showing the actual amounts of water which have been obtained from various underground sources during recent years, will also be a useful guide.

I cannot do better than close this chapter with a quotation from an address by Mr. W. Whitaker, F.R.S., recently delivered at the anniversary meeting of the Geological Society. He says: "Underground water is

indeed a very complicated and difficult subject, making strong calls on our reasoning powers. In the case of springs and streams we are dealing with facts, things that anyone can see; but in the case of underground water it is a very different matter; we have to make inferences, and though our inferences may be warranted by all that is known on the subject, yet it is seldom that we can speak with certainty. There is, therefore, a certain charm in questions as to underground water that is wanting in the more prosaic subject of surface-waters.

"The source must be some permeable formation of good thickness and with a broad outcrop, as the quantity of water in any permeable bed must depend on the amount of rain that falls upon it, and this latter greatly on the area of surface exposed. A well, therefore, must either be upon the formation that is to be the source of supply or upon some overlying formation through which it can be carried to the water-bearing stratum. These two classes of wells sometimes differ greatly.

"In the first case, the well should be at a part towards which underground water flows: away, therefore, from an escarpment or ending-off of a formation, and towards the line of outcrop or where the next overlying formation comes on. It should also be in low ground, as a rule, so as to avoid needless depth. In the second case, when a well has to be taken through some thickness of overlying beds to reach the water-bearing bed, different conditions sometimes arise, unless the well is near the outcrop of the water-bearing formation.

"The method of flow of water through the rocks must also be considered. In some, this is mostly through the pores or the spaces between the particles of which the rock is built up; but in some water-bearing rocks very little passes in this way. Sometimes the planes of bedding afford a sort of channel, but at others these are closed and well packed together. Often the flow is along joints, or

structural planes that have been formed after consolidation: fault-planes may act in a like way.

"Though, of course, every opportunity of studying the rocks at the surface should be taken, it must not be expected that they will show the same features when found at great depths, beneath a thick mass of overlying beds. Often it is ascertained that beds which are fairly open in sections that can be seen have their fissures, etc., more or less closed up below ground: for instance, at Richmond, where the Chalk has been worked horizontally under a great depth of Tertiary beds (from a little under to a little over 300 feet), a very great length of gallery has been driven with the result of cutting comparatively few fissures, and none of those large, so that but little water has been got; while in the waterworks for Southampton, placed on the Chalk close to its outcrop, so that there was no occasion to sink to a great depth, a very much less amount of gallery has yielded a very much larger quantity of water.

"Moreover, the Kent Company, which gives our largest supply solely from wells, has done comparatively little in the way of driving galleries, but has depended largely on simple wells and borings, which are either on bare Chalk or where there is no great thickness of other beds above the Chalk.

"Again, the underground condition of a rock may vary greatly in places near together. The Brighton Waterworks give a good example of this; for, while at the Lewes Road Station the fissures in the Chalk are many and small, in the Goldstone Bottom Station, not far to the west, the fissures are mostly large, but few. Yet the two stations are at about the same horizon in the Chalk, and there is no apparent reason for this difference between them. A somewhat similar case is that of Croydon, where the old works in the town give a much larger supply, without galleries (or at least with merely short connexions between

the wells), than that which is got from the new works, but little lower in the Chalk, at Addington, where there is a great length of gallery.

"These are cited as illustrations of the uncertainty of underground work, an uncertainty with which many of my engineering and some of my geological friends are fairly familiar; and they should prepare us to be somewhat cautious in predicting, at all events before we know.

"Not only do we find that beds pierced at great depths often have a character different from that which they put on at their outcrop, but also that waters found at great depths often vary much in their mineral contents from those in the same beds much nearer the surface. A well-known case of this sort is that of the waters in the Chalk under London, where the Chalk is thickly covered by Tertiary beds, those waters differing greatly from the waters in the bare Chalk northward and southward, in the increase of alkaline salts and the decrease of lime-salts.

"Other like cases have been described in waters from Jurassic beds, as at Swindon and at Woodhall Spa, in both of which a large amount of common salt occurs, while in the latter case there is a regular mineral water. It is found, too, that waters in wells from the sandy beds of the Wealden Series often contain a goodly proportion of carbonate of soda.

"Such matters, and the occurrence of mineral waters generally, point to the need of alliance with chemists, and the advantage of getting full analyses of well-waters, which show the mineral contents and do not merely refer to organic purity or impurity. With this help we may be able not only to trace the origin and history of a water, but may also some day learn something of those slow, quiet, unseen changes that go on underground, through the agency of water in the rocks: a subject of which, I think, we know little as yet, at all events in this country."

It is advisable in all cases to derive the whole supply

required from one and the same source. In many towns, especially on the Continent, water is derived from a number of different sources. This may have been due to the original supply proving inadequate on account of the increase in population and the increased consumption of water required by a higher standard of cleanliness. In Paris a dual system of supply has been adopted. The one furnishes unfiltered river water, and is used for municipal purposes and for supplying baths, fountains, etc. The other furnishes a purer water, derived chiefly from springs in the valley of the Vannes. The suggestion to adopt such a dual system elsewhere has not been favourably received. Apart from the enormous additional expense necessitated by a duplicate system of mains, it has many other objectionable features. At Berlin the water of the Spree, after filtration, supplies a portion of the inhabitants, whilst others are supplied from the Tegeler Lake. Vienna derives water from springs in the Styrian Alps and from wells sunk in the subsoil on the banks of the Schwarza. The water supply to Brussels is most unsatisfactory, and is derived from the subsoil, from the Harre, and from the drainage of the Forests of Soignes and Cambre. The Leipzic waterworks present several peculiarities. Water from the Pleisse is run into reservoirs, and the water filters through the natural gravel bottom, and is collected in earthenware pipes, with open joints, which are laid in the subsoil for this purpose. This supply is supplemented by the yield from five groups of Artesian wells. The water supplying Stockholm is derived in part from a lake and in part from the subsoil, almost exclusively from the latter during the winter months. Interesting details of these and other works are given by Palmberg and Newsholme in their *Treatise on Public Health and its Applications in different European Countries.*

CHAPTER XVIII.

THE PROTECTION OF UNDERGROUND WATER SUPPLIES.

NOTWITHSTANDING the immense progress which has been made in this country in recent years in practical sanitation and in sanitary administration, outbreaks of preventable disease due to the pollution of water-supplies have been all too frequent. Common sense suggests that if it is desired to obtain a pure supply of water, a source should be selected, removed as far as possible from any contaminating agencies, and that every reasonable precaution which science or experience can suggest should be taken to prevent either wilful or accidental pollution. At present only underground sources are being considered, waters derived from streams and rivers being discussed later. Both, of course, are derived from the same source—the rainfall—but the modes by which they may become polluted are somewhat different, and the precautions which require to be taken to prevent pollution are also different. Whilst streams are fed in a great measure by the rainfall which has not penetrated the ground, but merely run over the surface, the subsoil water and the water in the deeper pervious strata is derived entirely from the rainfall which has been absorbed by the soil, and which has percolated to the depth at which it is found. It is obvious, therefore, that the collecting areas in the two cases must be very different in character. The one requires an impervious or but slightly pervious strata, the other a pervious surface. The pervious surface will almost certainly, in this country

at least, be tilled for agriculture, and more or less highly manured. Such manurial matters as are soluble will be dissolved by the rainfall, and the finer particulate matter will become suspended in the water. All underground waters, therefore, are more or less liable to pollution at what may be regarded as their source, the rain which has fallen upon the pervious ground, and if they did not afterwards undergo some efficient process of purification, underground sources would have to be abandoned. In shallow wells constructed near houses the water is frequently very impure, and is notoriously liable to specific pollution, a large proportion of the outbreaks of typhoid fever recorded in this country being due to the use of shallow well water. Too great proximity to houses and sewers can be avoided, but that no house drainage or human excreta shall be placed upon the gathering ground is a matter beyond control. Circumstances, therefore, compel the use of water liable to specific pollution, and the point for consideration therefore is, Can this water undergo naturally such a process of filtration as will render it for all practical purposes absolutely safe for domestic use?

The word "filtration" rather than purification is here used intentionally, because the specific material which has to be removed from the water is not something in solution, but particulate matter in suspension, and as has been already remarked this particulate matter, though of extremely minute dimensions, is capable of being removed by filtration. This particulate matter also must be living, and there is every reason to believe that neither the typhoid nor the cholera organism can survive more than a limited time in water, especially if the water be free from polluting matter, and that they will not live long in unpolluted soil. If therefore the subsoil can so filter the water passing through it as to remove these living organisms, or if these organisms in traversing the subsoil find themselves in such an unfavourable environment that

life is impossible, it is obvious that water which has percolated through a sufficient depth or flowed longitudinally through a sufficient thickness of the subsoil, will contain none of the specific organisms, and can be used without risk of producing these specific diseases. The water which falls upon the surface of a porous soil tends in a downward direction until it reaches the level of the subsoil water. It then takes on a lateral direction, flowing through the interstices in the stratum towards its natural outlet, whether this be a well-defined spring, a flowing stream or the ocean. During its progress the organic impurities at first absorbed are more or less completely removed. The organic matter in solution becomes oxidised or " burnt " up, and we find the ashes, carbonates, nitrates, sulphates and phosphates only in the water if the oxidation has been complete. The living organisms are more or less completely removed, in part by the natural filtration and in part probably by other agencies which cause their destruction. A water originally very impure, and specifically polluted, may become hygienically pure and wholesome by passing through a sufficient thickness of subsoil. The upper portions of the soil, to which air has comparatively free access, especially if covered with vegetation, have the most powerful action. Nitrifying organisms abound, and convert the dead organic matter into simpler inorganic compounds, and the living organisms are more or less completely filtered out. So complete may be this purification that from properly constructed deep wells water may often be obtained almost, if not absolutely, free from organic matter, living or dead. These natural purifying processes have not as yet been sufficiently studied, but sufficient is known to enable fairly safe conclusions to be drawn as to the means which must be adopted to obtain a pure water supply from underground sources.

Before referring more fully to these natural processes of purification, the brief consideration of the sources of

underground water supplies known to have caused outbreaks of typhoid fever or cholera will prove instructive. The late Dr. Ernest Hart prepared a historic summary of local outbreaks of typhoid fever in Great Britain and Ireland, occurring between 1858-1893, due to specifically polluted water, which summary contains a tabulated analysis of 205 epidemics. Considering only those due to the use of subsoil water—and these form about two-thirds of the whole—it will be found that nearly all were due to the use of water derived from shallow wells situated within a very few feet of defective cesspits, leaky cesspools or sewers. Take two examples selected at random from the more recent outbreaks. "Well sunk in gravel with strong clay watertight bottom. Drain ran close to the well used by the first patient and leaked into the well. Evacuations thrown into the common ashpit and adjacent sink. All wells in the locality open to the same water movement and sunk in soil charged to overflowing with impurities of every kind." Or again, referring to a much more serious epidemic, "Water supply obtained from three wells with three headings, two headings serving as connecting tunnels between the three wells. The heading driven from one well only in the early part of the year, a large fissure struck, the inrush of water being so great that the men in the tunnel had to fly for their lives. Soil overlying the chalk in which were sunk these wells liable to sustained pollution by sewage." With each outbreak the same story is related. Wells sunk in a sewage-polluted subsoil, near drains, sewers, or cesspools, or in a fissured stratum, the fissures of which communicated more or less directly with the source of pollution. In no instance is there a record of an outbreak being produced by water derived from a well sunk in a carefully selected site, and in which the simplest precautions had been taken to prevent pollution. The wells were so situated that anyone possessing a smattering of knowledge of sanitary matters would have

said that sooner or later they would become specifically infected and an outbreak of disease result. If the various reports upon outbreaks of cholera are consulted the same conditions are found, the absence of all precautions, and the source of fæcal contamination easily traceable. The evidence gained from dearly bought experience is in each series of cases the same.

Professor Pettenkofer has long taught that a polluted soil is the best nidus for the propagation of the typhoid bacillus, and Dr. Hauser, of Madrid, expresses similar views with reference to the cholera bacillus. That the soil is the natural nidus of these disease-producing organisms outside the human body is now generally conceded, but there are soils and soils, and to explain all the facts it is necessary to assume that only certain soils are favourable, and that in others the conditions are so unfavourable that multiplication therein is impossible. The favourable soils appear to be those which contain organic matter, especially of animal origin, sewage and excremental matters generally. The unfavourable soils are those which contain least organic matter, and more especially are free from sewage pollution These, of course, are not the only factors, but they are the only ones bearing directly upon the subject under consideration.

In an investigation made on behalf of the Local Government Board, a preliminary report of which has recently been published, Dr. Sidney Martin found that the typhoid bacillus and the colon bacillus (an organism allied to the typhoid bacillus, and found in large numbers in all sewage matters) rapidly increased in the sewage-sodden soil from Chichester, whereas in virgin soil under similar conditions they very speedily died out. When black mould containing organic matter was used, both bacilli retained their vitality for a considerable period, whereas in none of the experiments with virgin soil did any growth whatever occur. Still more recently Dr. Robertson has published the results

of a series of experiments conducted at St. Helens, of which town he was the Medical Officer of Health. The results were very suggestive, and proved that the typhoid bacillus was capable of multiplying rapidly under certain conditions. He inoculated a large quantity of broth with the typhoid bacillus, and with this infected various patches of ground. Upon the patches which were manured with dilute organic solutions the typhoid bacillus throve lustily, upon the patches not so treated they languished and died. A very significant fact is also recorded by Dr. Robertson. When the ground was infected 18 inches beneath the surface the bacilli grew to the surface; when the surface was inoculated they only grew downwards to a depth of 3 inches. This inability of the rainfall to carry the organisms deeper into the soil, and the fact of the deep cultures growing upwards to the surface confirm the view that it is only in the surface soil that any active propagation can take place. At a little depth below the surface the conditions become so unfavourable that any growth which may take place is in an upward direction; at a greater depth probably no growth whatever would occur, and the organisms would quickly die.

Abba, Orlandi, and Rondelli * have recently conducted certain investigations at Turin to test the filtering power of the subsoil from which the water supply to the city is obtained. For this purpose they used diluted broth cultures of *Bacillus prodigiosus*. They found that this bacillus penetrated to a depth of 3 metres (about 10 feet) but did not pass into the ground water save after heavy and persistent rains.

Whatever may be the explanation, there is much evidence to prove that at a very limited depth beneath the surface of a compact porous soil the subsoil and the subsoil water are practically sterile. Koch appears to attribute this to

* *Zeitschrift für Hygiene*, vol. xxxi., 1899, p. 66. Abstracted by Dr. McWeeney in *Journal of State Medicine*, vol. viii., p. 47.

a mere process of natural filtration, since in his paper on "Water Filtration and Cholera," he says, "Rain water when it sinks into the ground and ultimately becomes subsoil water passes through far thicker layers and with far less rapidity than river water when passing by artificial filtration through sand filters. If the sand is only sufficiently granulated we have in soil filtration a much more perfect process than is at our disposal in artificial filtration. This is confirmed by the investigations of C. Fraenkel, who has shown that subsoil water, even in a soil which has been much and for a long period contaminated, as in the case of Berlin, is quite free from germs. In other places the same results have followed from investigations made on this point." Quite recently I have confirmed these observations in some experiments made with sand taken from various depths beneath the surface. Up to a depth of about 4 feet organisms were present, but at 4 feet they appeared to be anaerobic, below 5 feet I could not find any organisms whatever.

The bacterial purity of subsoil water, however, is not altogether due to the efficiency of the natural process of filtration. No doubt the conditions which obtain underground are very unfavourable to the growth of many organisms, and there is abundance of evidence to prove that the bacteria producing typhoid fever and cholera are in a more or less unfavourable environment when in water, and can only survive for a very limited period. Most of the experiments recorded, having reference to the vitality of the typhoid bacillus in water, have little or no bearing upon the subject under consideration, the conditions under which they were conducted being so different from those which obtain in nature. Others again are unreliable on account of fallacies underlying the methods of examination adopted. This question of survival is a point of the utmost importance. Again, as far as is known, typhoid fever and cholera are exclusively human affections, and

there is no evidence to prove, nor are there any recorded facts which necessitate the assumption, that cattle of any kind suffer from these specific diseases and discharge excremental matter capable of specifically infecting the soil.

The remarks already made with reference to soil pollution apply equally to those cases in which the source of pollution is beneath the surface, as to those in which the filth is deposited upon the surface. Fortunately all sewage contains microbes which, during their growth and development, tend to break down the dead organic matter upon which they subsist, into simpler and more stable forms, that is to say, under suitable conditions sewage will purify itself. This fact, which is only just beginning to be recognised, is being taken advantage of for the purification of sewage, in the so-called bacterial filters of Dibdin, Ducat and others. Everyone who has had to watch the process of excavation in the vicinity of defective sewers and cesspools has observed that there is little or no evidence of pollution in the subsoil, except in the immediate vicinity of the defects which permitted the pollution. This purifying action of the subsoil is easily demonstrated on any fairly large patch of drift upon which a village stands. On the side furthest from the natural outlet of the water, the wells yield what may be called the normal water of the patch, containing very little organic matter and only comparatively small quantities of chlorides and nitrates. Within the village many of the wells will be found to be highly polluted, but almost invariably some will be found which, either on account of their better construction or their greater distance from a source of pollution, are also practically free from organic matter, though containing large quantities of chlorides and nitrates. On the side nearest the natural water outlet the same condition is found, the only evidence of the previous pollution being the ashes of the consumed organic matter. Besides the chemical change the natural process of filtration has taken

place. Subsoil water travels horizontally at a very slow rate indeed, compared with the rate at which water is passed through artificial filter-beds, and it is practically impossible for particulate matter, living or dead, to be carried any distance by the current.

In certain places, however, the subsoil water may flow with an appreciable velocity, and in channels more or less defined. The reason for this can easily be understood. Suppose that a valley scooped out of some impervious stratum, such as the London clay, were to become obliterated by being filled with sand and gravel. A portion of the rainfall upon the now exposed area would percolate into the sand and tend towards the centre of the original valley, finally making its way to the lowest point. The greatest flow would be along the bottom of the valley, and doubtless here in the course of time, it might be ages, the resistance would diminish from the washing away of the finer particles, and after reaching this channel, possibly no further purification or filtration would take place. Herein lies one of the dangers of the use of subsoil springs. These springs are but the natural outlet of the subsoil water, and impurities entering the subsoil immediately over the line of flow are much more likely to be dangerous than impurities entering elsewhere. The nearer the spring or the line of flow the greater the danger and the greater the need for protection. In the neighbourhood of rivers also, there is often a considerable flow of water in the subsoil, rendering it necessary to direct particular attention to the protection of the ground above the point at which water is being abstracted.

So far it has been taken for granted that a subsoil of uniformly compact consistence was being considered, such as deposits of drift, beds of sandstone, etc.; but there are other pervious water-bearing strata, of which chalk is the best example, which are not uniform, but full of fissures. It is obvious that water which has once entered these open

fissures will undergo little further chemical filtration, and that polluting matters may be carried great distances therein. Here again, however, the upper surface of such a stratum is almost certain to be fairly compact, the fissures being obliterated by the surface soil, and water passing through will be more or less completely purified. In travelling along the open fissures, the velocity of flow (save in the immediate vicinity of the natural or artificial outlet) must be very slow, giving time for sedimentary matters to be deposited, and for such organisms as the typhoid and cholera bacilli to die and be carried down therewith. Water collected from deep wells in fissured strata, at points many miles removed from the exposed collecting area, is usually found to be particularly free from organic matter, and to contain few if any bacteria; but the freedom with which water can traverse these fissures has too often been painfully obvious in counties near the coast, inasmuch as wells—sunk at great cost—have had to be abandoned on account of the rapid infiltration of sea water. By continuous pumping, the water level had been so depressed that a return current from the sea was set up. The area which may be directly drained by a well in a fissured stratum is therefore enormously larger than that which can be affected in a uniform porous stratum.

To ensure a continuous supply of hygienically pure water from an underground source, many points have to be taken into consideration; and no general rules can be laid down applicable to all circumstances. There are many wells used for large public supplies which ought to be abandoned, on account of their proximity to groups of dwelling houses. In many cases these houses have been erected since the works were established; too small an area of land was acquired in the first instance, and the mistake cannot now be rectified. There should be an area of ground around each such well under the absolute control of the purveyors of the water. The well should be con-

structed so as to admit water only at the lowest point possible. If the pumping machinery is in or over the well care should be taken to prevent dirt of any kind, especially from the workmen's boots, reaching the water. The immediate vicinity of the well should either be uncultivated or laid down to grass, but not fed. An outer ring should be similarly laid down, but cattle might be permitted to feed thereon. These two rings may be called the inner and outer protective areas, and the inner ring should be so enclosed that no one can enter "except on business." The area of this inner ring should be, at least, as large as the area of the cone of depression produced by the pumping. For example, suppose that 45,000 gallons are being pumped per day from a sandy subsoil, and that the depression of the water level in the well caused by the pumping is 9 feet. Each cubic foot of the saturated sand would yield about 1½ gallons of water. To yield the 45,000 gallons therefore, 30,000 cubic feet of the subsoil would be drained. The cone of depression having a depth of 9 feet, the area of its base would be 10,000 square feet, representing a circle with a radius of 57 feet, the well being at the centre. The cone, however, has not straight sides, and to be perfectly safe therefore a radius of 30 yards had better be allowed. The outer protective area should have a radius double or treble that of the inner area.

In a uniform subsoil the rapidity with which the water travels toward the well decreases as the square of the distance. If within 3 feet of the well the movement of the water is at the rate of 1 foot per second, at 30 feet the movement of the water will only be at one one-hundredth of that, or 1 foot in 100 seconds, and at 30 yards the rate will be 1 foot in 900 seconds. Therefore, at a certain distance away from the well the movement of the water is so slow that perfect filtration is secured. That is to say, the water passes through the subsoil very much more slowly than it passes through the sand in an ordinarily

constructed filter, and for that reason the protective area need not extend, assuming my views to be correct, more than a limited distance round the well.

I am strongly of opinion that this protective area should in future always be insisted upon, but its extent may have to be defined in each individual case. The conditions vary so greatly that no general rule can be adopted. In deciding, many factors have to be taken into account: the contour of the ground, the depth and nature of the subsoil, the height of the subsoil water and the range of its fluctuations, the possible sources of pollution, the amount of water to be abstracted, etc. The direction of the flow of the subsoil water must also be considered, since polluting matter entering the soil on the side upon which the water is flowing towards the well is naturally more dangerous than if it enters on the side where the flow is from the well. Naturally also a much larger protective area will be required where the subsoil water is only a few feet from the surface, than where it is 15 to 20 or more feet below. Where the underground water is known to be flowing in a fairly well defined underground channel, the protective areas had better be elliptical, the longer axis having the direction of flow, the well being on this axis but nearer the end towards which the water is flowing. This elliptical protective area will in most cases be desirable for springs, for reasons which are so obvious as not to require enumeration.

In many instances the protection of the water is rendered more difficult, and the problem becomes more complex, from adits or collecting channels being driven or trenched in one or more directions in order to increase the available supply of water. These drains should be laid as low as possible. Only under exceptional circumstances should they be less than 10 feet deep, and the trenches should be very carefully filled in and tightly rammed. The whole

of this trenching should be well within the inner protective area.

Where the subsoil is fissured the danger of pollution is greater and protection more difficult, since the source of the danger may be concealed and may almost defy detection. A striking example of these dangers was furnished by the outbreak of typhoid fever at New Herrington, Durham. Any fissure so directly connected with a well would probably give indications of its existence soon after heavy rains by the effect upon the water in the well by rendering it more or less turbid. In all cases where such turbidity is produced, however slight, there is cause for anxiety, and both the well and its surroundings should be examined to ascertain the cause. If a heavy rainfall can wash into the well visible particles it could still more easily carry with it the minute organisms which cause disease, should such unfortunately happen to be within its sphere of influence. Surrounding such wells there should be protective areas, but their form and dimensions could only be defined after a careful survey of the district, more especially with reference to the dip of the stratum, and the general direction of the fissures. The locality where any fissures were suspected of reaching near the surface would require an especially careful examination. If within the well or adits there were numbers of fissures yielding water some useful information might possibly be obtained by an examination, chemical or chemical and bacteriological, of the water from those flowing most freely. Such wells require careful watching, and frequent systematic analyses should be made to ascertain to what extent, if any, the quality of the water is affected by the rainfall. The greater the variation the greater the risk, especially if the variations rapidly follow the rainfall and are accompanied by an equally rapid variation in the flow. If the variations in character and quantity are but slight, and only occur some time after the rainfall, and especially

if there is never any indication of turbidity, then the risk is a minimum and may possibly be ignored.

Deep wells drawing water from subterranean sources overlaid by thick beds of impermeable clay are generally considered to yield the purest and safest of waters. Doubtless where the site has been judiciously selected and the well carefully constructed, such is the case, but deep wells as well as shallow wells may be defective in construction and admit of pollution taking place. Wherever constructed the gathering ground feeding it must be some distance away. This outcrop should be examined, the more carefully the nearer it is to the well. It is desirable to know if any possible sources of danger exist, even if they cannot be removed, especially if within one or two miles of the well. At a further distance, possibly they may be neglected as powerless for harm, the time which would elapse between the rainfall reaching the ground surface and the well being ample to secure a satisfactory purification. The chief source of danger is from the admission of possibly polluted subsoil waters. It is often difficult to effectually block out the water from superficial strata, but it can be done, and should be done. For further security there should be a small protective zone kept free from all pollution. Greater care also should be taken within the well to prevent dirt, especially from the shoes, defiling the staging and being washed into the well. Samples of the water collected on a uniform plan, and at regular intervals, should be submitted to analysis and careful records kept. For this, however, to be of real service the water must be derived entirely from the deep source. If there is a variable admixture with subsoil water, the value of the analytical record is greatly decreased. Such careful and systematic analysis will detect any variations in the character of the water, and possibly sound a note of warning on the approach of danger.

Where bored tube wells are used and the tube forms the

suction pipe of the pump, danger of insuction of subsoil water, possibly contaminated, certainly exists and should be carefully guarded against. The action of the pump is to withdraw the atmospheric pressure from within the tube, and the excess of pressure outside will force air or water through the most minute defect, through apertures so minute that under ordinary circumstances neither would have passed. When this action has once been set up, the openings are bound to increase in calibre and insuction becomes still more easy.

Whilst the deep wells constructed to supply large communities are usually carefully made, sufficient care does not always appear to be taken in the construction of deep wells when only intended to supply a farm or a few cottages. I have known several hundreds of pounds spent in boring and sinking such a well, and then, to save a few additional pounds, the sunk portion has been so defective and the top so badly protected that the water has become polluted.

Whether underground water be drawn from a superficial or deep water-bearing stratum, there is no doubt that the chief factor in protecting it from pollution is the provision of an area round the well or point of collection which is under the control of the owners of the well, and which is kept free from all matters of an objectionable character. In the past too little care has been taken, but it is tolerably certain that in future both Parliament and the Local Government Board will insist upon efficient protection, and the provision of ample protective areas. Existing sources of supply should be examined and steps taken to secure the necessary protection when this is defective. If such is not possible—and in some instances this will probably be found to be the case—efforts should be directed towards providing a less dangerous source of supply. It will be better to voluntarily abandon the works now than to wait until an outbreak of typhoid fever or cholera arouses public indignation and compels their abandonment.

Finally, all public supplies should be periodically examined even to the minutest detail and the results recorded. These inspections should be supplemented by chemical or chemical and bacteriological analyses at more frequent and regular intervals. Were the precautions above indicated universally adopted, I am convinced that there would no longer be any fear of the specific pollution of our underground water supplies, and that one of the most frequent causes of the epidemic prevalence of cholera and typhoid fever would cease to exist.

CHAPTER XIX.

THE PROTECTION OF SURFACE-WATER SUPPLIES.

MUCH more attention has been given in recent years to the protection from pollution of river, spring, and well water, than to the protection of surface-water sources of supply. This is doubtless due to the fact that all the recent large outbreaks of typhoid fever have been due to the use of river or spring water, and the smaller outbreaks to polluted shallow wells.

Reference to the Local Government Board and other reports on outbreaks of typhoid fever shew that surface-water collected on a large scale for the supply of a town or series of towns or villages has rarely been charged with the spread of that disease. This is a subject of congratulation to those towns, so numerous in the north of England, deriving their water from such sources. I attribute this immunity entirely to one cause, the storage of the water in large reservoirs. The storage usually amounts to from 100 to 200 days' supply. During this storage the water is fully exposed to the air for oxidation, and to sunlight for insolation, and the long period of rest secures more or less thorough sedimentation. I feel tolerably certain that the typhoid organisms, if introduced into such a reservoir, have but a remote chance of surviving and reaching the water mains in a living condition. The environment is distinctly unfavourable; the sunshine quickly kills them as they approach the surface, and by sedimentation they are deposited with the mud at the bottom of the reservoir.

We cannot be certain, however, that special conditions may not arise permitting such organisms to reach the mains; hence, apart from sentiment, no reasonable effort should be spared to prevent the pollution of the water by any matter which could possibly be infected. To secure at all times a thoroughly wholesome, bright, and palatable water should be the aim of every authority having control of any public water supply.

Where full control of the collecting area is secured and the whole converted into prairie land without houses or farms, mines or other works upon it, and with but few public thoroughfares, and the storage reservoir is of very large size, filtration may possibly be dispensed with, but although it ceases to be a very important factor, I should always regard it as highly desirable.

To obtain full control of a gathering ground is, however, a very difficult and often impossible procedure. The subject was thoroughly discussed recently before a Parliamentary Committee when a Bill was being considered in which a water authority sought to obtain this complete control. Partial control had already been obtained and many houses demolished. Certain farms had been acquired and laid down entirely to grass. There were many footpaths, certain highways, stone quarries, etc., and the evidence showed that so many interests were involved, public and private, that absolute control was impossible. People walking along these footpaths and roads in secluded districts cannot be prevented from obeying the calls of Nature. Accommodation may be provided at quarries, but no one can compel the men to use them and them only. Hence when all has been done there are risks which must be run and against which some other mode of protection must be devised. In this country, which is becoming more and more thickly populated, and where even the most remote districts have charms for tourists, I doubt very much whether any upland surface can be kept absolutely free from pollution.

Ample storage may possibly be in many cases a sufficient safeguard but, as we shall see shortly, there are other reasons for preferring filtration also.

There are many gathering grounds, however, where such efficient protection is impossible, and where a certain amount of pollution by manurial or sewage matter is unavoidable. These are districts in which more or less of the land is under cultivation. The land may be so valuable that purchase is out of the question, or there may be other insurmountable difficulties with reference to its acquisition.

Even in these cases very often great improvements may be effected by efficient supervision of the sanitary arrangements, scavenging, etc., by constructing drains and sewers to convey the polluting matter beyond the boundary of the watershed, by arranging that no manure containing human excrement shall be used. Where such arrangements cannot be made the question must arise as to whether the watershed should not be abandoned or whether the storage with filtration can be depended upon for preventing any infective matter reaching the mains. Every case of this kind must be discussed on its merits, and after a thorough and systematic examination of the watershed. I have seen reservoirs inefficiently protected and with footpaths along the banks. On these footpaths I have seen human excrement, and in the water I have seen drowned animals. It is obvious, therefore, that so far as is possible both animals and human beings should be prevented from gaining access to the reservoirs. Sometimes the water from such an unsatisfactory collecting area can be utilised as compensation water for manufacturing purposes.

Where surface-water supplies are used a large storage is always necessary, in order to impound water during the wet seasons for use during the dry. This alone assures storage sufficient for hygienic purposes, for bleaching, more or less completely, peaty waters, for allowing sedimentation, and time for the destruction of the typhoid microbe. The

greater the storage, the better for all these purposes. As previously stated, such storage is probably sufficient, save under very exceptional circumstances, to insure safety. If the water gets very low, however, in the early autumn, and very heavy rains come on suddenly, it is quite possible for impure water to reach the mains. After a long dry season, polluting matter, if any, would accumulate on the watershed and be washed down with the first storm. The water then would be unusually polluted, and it would have unusual facilities for rapidly traversing the storage reservoirs, and reaching the consumers. Efficient filtration would now be the last and only line of defence.

Filtration, efficiently conducted, would at such times prevent 99 per cent. of the organisms from entering the mains, and experience teaches that the risk of using such a water, properly filtered, is very small indeed. But apart from protection from infection filtration is almost indispensable, if we wish at all times to supply a bright and palatable water. We cannot prevent low forms of vegetable and animal life being carried into the reservoirs, nor can we prevent their multiplication therein. If the water is not filtered, these are delivered with the water to the consumers, and impart to the water an unsightly appearance, and sometimes a very disagreeable odour. Even when not visible at the time of delivery, they may so rapidly multiply afterwards, that vessels in which the water has stood for a night or two become coated with a more or less slimy deposit, or with a distinct green growth. This condition is one which frequently causes loud complaints, and such a water cannot be regarded as sufficiently satisfactory for a public supply.

To sum up, I strongly advocate three distinct lines of defence:

1. The utmost possible control of the watershed or collecting area.
2. Very ample storage.
3. Sand filtration.

Where the water is acid, or has a plumbo-solvent action, the filtration should be through a mixture of sand and limestone, and the softer the limestone the better, the object being to neutralise the acid and cause the water to dissolve a small quantity of carbonate of lime, as by this means the plumbo-solvent action is more or less completely destroyed.

The Local Government Board has recently issued a circular bearing upon the protection of water supplies, and suggests that every sanitary authority should obtain accurate information in such matters as the following:—

1. *Where water is derived from gathering-grounds or from springs.* Whether drainage from human habitations, farm-yards, and the like finds its way directly or indirectly into the reservoir or to any part of the water service, and whether risk of access to the water of human excreta and similar refuse is likely to arise.

2. *Where water is derived from deep wells.* Whether surface or other water liable to be contaminated by drains, sewers, cesspools, and the like reaches, or is liable to reach, the wells. The existence and direction of fissures in the strata deserve especial consideration in this respect.

3. *Where water is derived from shallow wells.* Whether the wells are so circumstanced that they run risk of contamination by reason of drains, privies, cesspools, or middens, or by the deposit of manure—whether derived from human excreta or not—in or on the ground in the neighbourhood of the wells.

The district councils are reminded that they are responsible for the wholesomeness of water which they themselves supply, and that they should by careful inquiry make themselves acquainted with the sources, nature, and quality of the various supplies in all parts of their districts.

This circular letter would have been more complete had it also directed attention to section 7 of the Public Health (Water) Act, which renders it obligatory on the part of

every rural sanitary authority from time to time to take such steps as may be necessary to ascertain the condition of the water supply within their district, and authorises the payment of all reasonable costs and expenses incurred by them for this purpose.

CHAPTER XX.

WELLS AND THEIR CONSTRUCTION.

The practice of obtaining water by means of wells sunk in the subsoil is one which dates from the remotest antiquity, and at the present time a very large proportion of the population of the globe derives its supply of water from such sources. In Great Britain it is estimated that over one-third of the population is so supplied. Whilst in every other department of engineering improvements have advanced with rapid strides, especially in recent years, shallow wells continue to be constructed in almost precisely the same way as they were thousands of years ago. The well-sinker is the most conservative of men, and in most districts it is impossible to get a well constructed so as to protect the water from pollution. To the country well-sinker a well is merely a reservoir to contain water, and whether this water enters from the bottom, side, or top he considers a point unworthy of consideration, and in fact he makes the well in such a manner that water can freely enter it at all points. The result is, that as wells are, for convenience, almost invariably sunk in close proximity to inhabited houses, impurities from the soil, from defective drains, cesspits, and cesspools readily gain access and foul the purer water which enters at a greater depth. It is not surprising therefore that the great majority of such wells yield water which is always impure, and liable at any moment to become specifically contaminated and produce an outbreak of disease. The time-honoured custom of

lining the well with bricks, set dry, and resting upon a wooden curb, still almost universally prevails. The brickwork may be carried right up to the surface and the well left open, or it may be covered with a lid, in which case it is frequently so left that the water spilt upon withdrawing the bucket runs back into the well, carrying with it filth from the surface of the ground around, and during a heavy rainfall the surface water runs directly into the well. Where the well is covered up, the cover is generally near the surface, and may consist of old railway sleepers or logs of wood admitting water freely. Even if no sewage matters enter such wells, the wooden curb and the rotting wooden covering yield putrid organic matter to the water. Draw wells and dipping wells are also liable to be contaminated by the dirty vessels let down into them, by frogs, rats, and other animals getting in, and by dead leaves and other matters blown by the wind. The animal and the vegetable substances by their death and decay foul the water. In wells otherwise carefully constructed it is often found that impure water can gain access along the track of the pipe leading from the pump to the well.

In a properly-constructed well no water should be able to enter except from near the bottom, so that before reaching the well it must have passed through a considerable thickness of subsoil, becoming in its course thoroughly filtered and purified. Various methods of accomplishing this difficult task have been suggested; but as there are other ways of obtaining subsoil water, which are more simple and far more satisfactory, we may reasonably hope that ere long the ordinary form of shallow well will be abandoned. Before describing these other methods, however, the best ways of constructing wells may be briefly referred to. Where the excavation is through solid rock, such as chalk, limestone, or sandstone, the steining, or lining with a cylinder of brickwork or of iron or other material will only be necessary to keep out the water from

the more pervious surface soil. If bricks be employed they must be well bedded on the rock with cement, and the whole of the brickwork lined inside with hydraulic cement, and the lining continued some distance below the last layer of bricks on to the exposed surface of the rock, so as to render the junction as impervious as possible. The brick-work should also be well puddled behind. Where the rock is not freely porous water may accumulate in the loose subsoil, and unless the greatest care be taken it will enter the well. In the most modern wells cast-iron or wrought-iron cylinders are employed for lining the upper portion in order to keep out the surface water and land springs. Similar cylinders are also employed to keep out water from fissures which may be met with in excavating the well. Where the subsoil is clay and impervious these precautions are of course not necessary. In ordinary wells, sunk throughout in a porous subsoil, the lining should consist of two separate rings of 4½-inch brickwork laid in cement and lined with cement to a depth of 10 or 12 feet from the surface. As this class of work is somewhat expensive, and the cement is liable to fracture, either by the inward pressure of the sides of the well or other causes, earthenware tubes are now being made by the Leeds Fireclay Company for lining purposes. The ground having been excavated as deep as can be done with safety, a tube is dropped in and some well-puddled clay laid on the bevelled edge and another tube lowered. If properly driven the tubes fit well together. The tubes are lowered by aid of ropes, blocks, and cross-bars. Having got in the tubes, a man can easily work inside and undermine the edge, when the weight will cause them to descend. Of course the joints are afterwards "pointed" inside with cement so as to make them more secure, and it is advisable to try all the tubes, fitting and marking them before using. Or the well may be constructed in the ordinary manner, dry steined with 4½-inch brickwork if necessary, and the tubes then lowered and

fitted and puddled behind with clay. Dry-steined wells at present in existence might with advantage be converted into tube wells in this manner. The well itself having been so constructed as to prevent the possibility of water entering anywhere except at the bottom, it remains still to cover it in and protect the top. The best plan is to project the dome of the well 6 or 12 inches above the surface of the ground and securely cover with a properly-fitting iron cover. By this means easy access is at any time gained for cleansing or examining purposes. The pump should be fixed some little distance from the well, and the drain carrying away the waste water should not go near it. Every care should be taken to render water-tight the aperture through which the pump pipe passes, and it should be bedded in clay or cement so as to prevent the water or rats forming a track alongside the pipe through which impurities can gain access to the water in the well. Probably the best plan is to solder a baffle plate to the suction pipe and imbed this plate in the side of the well. If the sides of the well be covered up to a sufficient height above the ground, the pump may be fixed inside, the handle and spout only projecting outside. A hooded aperture at the top can be left for ventilation.

Quite recently I have seen wells the upper portions of which were constructed from the halves of old steam boilers, the domed end of the boiler forming the top of the well and a hole being drilled through the side for the pump pipe to enter. To prevent the action of a soft water upon the iron, it is desirable that the whole of the interior should be lined with cement.

Koch, in his work on *Water Filtration and Cholera*, whilst condemning strongly the ordinary shallow well, recognises the fact that it is impossible to arrange that those already existing should be abandoned. He therefore recommends that the construction should be so altered as to remove all danger of contamination from above. "To achieve this,

one should proceed by filling up the well to the highest water point with gravel, and over the gravel with sand up to the very top." Of course an iron pipe should traverse the sand and gravel and be connected with the pump. A well so constructed "gives the same protection against the infection of water as is given by the sand filtration of the great waterworks. In fact it really gives a greater protection, since it is not exposed to the many disturbances in the process of filtration already referred to, and is also not affected by frost." So much attention is now being given to perfecting as much as possible the water supply of the great waterworks, that it is important not to lose sight of the domestic water supply by pumps and wells. By improving the wells in the manner explained above, "the spread of cholera,* in so far as it is due to water, can be restricted to a great extent. It is just in this respect that a great deal can yet be done." This suggestion of Koch's is one worthy of consideration, since the change can be effected at a minimum of expense, and the result leaves little to be desired. It is important, however, to remember that the superficial layer of sand should be at least 6 feet in thickness. Where the subsoil water is reached at a less depth than 6 feet, probably this method will not afford complete protection in many cases. Dr. R. Kempster, in his researches on "The influence of different kinds of soil on the cholera and typhoid organisms," arrived at the following conclusions: "White crystal sand, yellow sand, and garden earth have no marked favourable or injurious action on the life of the organisms The length of life of the organisms in the soil depends chiefly on the amount of moisture present. Peat, on the contrary, is very deadly to both the comma and typhoid bacillus. The soil acts as a good filter, holding back most of the organisms, but it is possible for these organisms to

* And of typhoid fever and other diseases disseminated by water.

be carried through $2\frac{1}{2}$ feet of porous soil by a current of water." Where the ground water-level, therefore, is within 5 or less feet from the surface, the side of the well should be rendered impervious to a depth of 10 or 12 feet, or, better still, the water should be obtained by aid of an Abyssinian tube well, next to be described, driven to at least this depth.

In a great many instances subsoil water can be obtained without the trouble and expense of well-digging, merely by driving iron tubes through the ground until the subsoil water is reached, and fixing a pump to the upper end of the tube. Such tube wells were first used systematically during the Abyssinian campaign, hence they are now popularly known as "Abyssinian" tube wells. They are most suitable for gravel, coarse sand, chalk, and similar porous water-bearing strata, and for depths not exceeding 40 to 50 feet, though under exceptional circumstances tubes have been driven successfully to a depth of 150 feet. Naturally they cannot be driven through hard rock, neither are they suitable for obtaining water from marl, fine sand, or clay formations, since the apertures in the perforated terminal tube are liable to become blocked by the fine particles of which such strata are composed. A pointed perforated tube is driven into the ground by aid of a "monkey." (The tubes vary from $1\frac{1}{4}$ to 4 inches in diameter, according to the amount of water which it is desired to raise.) When this tube has been well driven, a second tube is screwed on to the first and the driving resumed. By lowering a plummet down the tubes from time to time, it can be ascertained whether water has been reached or whether sand or earth is filling up the end of the perforated tube. When water is reached a pump can be attached and a sample drawn for examination, and the quantity available ascertained. If either the quantity or quality be unsatisfactory, the tubes can be driven deeper, or they can be withdrawn and redriven in another spot. A well of this

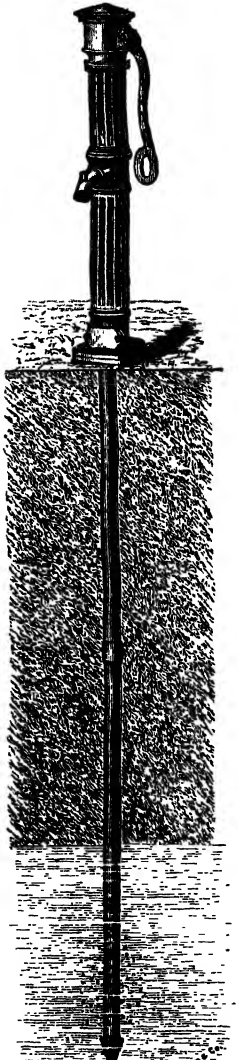

FIG. 20.—Abyssinian Tube Well.

character is shown in Fig. 20. Very often, where the supply from an ordinary sunk well is limited, it can be increased by driving one or more of the "Abyssinian" tubes from the bottom of the well. Special pointed and perforated tubes are employed where the soil is ferruginous or likely to corrode the metal of the ordinary tube. Tubes designed to prevent plugging with sand are useful under certain circumstances, as when the water-bearing strata contains together with the sand a fair proportion of grit. In fine sandy soils, however, it is better to withdraw the tubes, ram down a lot of fine gravel, and redrive.

In the "Abyssinian" tube well the water is drawn directly from the water-bearing stratum, there being no reservoir. At first the water invariably contains fine sand or chalk, according to the nature of the subsoil, but after a time a clear water is yielded. This is probably due to the removal of all the fine particles and débris from around the terminal tube and the formation of a natural cavity in which the water accumulates. In suitable localities these tube wells answer admirably, and not only are cheaper to sink, but yield a safer supply of water than a sunk well. 'One

man, usually, can drive the smallest-sized tubes, but three or four men are required for the largest tubes. In very light soil a 30-feet well may be driven in less than one day; in a firmer soil three days may be required. Whatever the depth of the tube well an ordinary pump will raise the water, provided the water level in the tube is within 25 feet of the surface. If the water stand at a lower level, a deep well pump must be provided.

The capacity of these tube wells varies with the depth, yield of spring, and power of pump applied.

The following are the estimates of two of the best-known firms of well-sinkers:—

Size of Well.	Yield in Gallons per Hour.	Authority.
$1\frac{1}{4}$ in.	150 to 600	Le Grand and Sutcliff
2 ,,	300 to 1,200	,, ,,
3 ,,	600 to 2,400	,, ,,
4 ,,	1,200 to 4,400	,, ,,
$1\frac{1}{4}$,,	150 to 900	C. Isler and Co.
2 ,,	300 to 1,500	,, ,,
3 ,,	450 to 3,000	,, ,,

Messrs. Le Grand and Sutcliff have kindly furnished me with the following table (see page 372), giving the depth of well, size of tube, yield of water per hour of a series of typical wells driven by them, which bear out the above statements.

Not only are these tube wells preferable to sunk wells on account of the greater freedom from risk of contamination, but they are much less expensive. The probable cost of a well can easily be calculated from the following estimates (see page 3[illegible]).

TABLE X.

"Abyssinian" Tube Wells (Norton's Patent).

Town.	Water-bearing Stratum.	Water Level.	Depth.	Diameter.	Yield per Hour in Gallons.	Sunk by	Date.
Beccles	Chalk	4′ 0″	84′	3″	3,000	Le Grand and Sutcliff	1879
Burnham, Essex	Sand and Gravel	23′	28′	3″	1,800	,, ,,	1899
Burton	,,	17′	25′	3″	2,400	,, ,,	1878
Chelmsford	Gravel	23′	33′	2″	720	,, ,,	1896
Dagenham	Sand and Gravel	9′ 6″	17′	1¼″	480	,, ,,	1898
East Stratton	Chalk	20′	34′	1¼″	480	,, ,,	1898
Gravesend	Sand and Gravel	10′	54′	2″	1,200	,, ,,	1879
Hereford	Gravel	17′ 6″	33′	3″	1,900	,, ,,	1881
Ilford	Chalk	4′	80′	2″	1,200	,, ,,	1896
Lechlade	,,	10′ 6″	22′	3″	3,000	,, ,,	1892
Lincoln	Sand	4′ 6″	31′	3″	2,000	,, ,,	1894
Melton Mowbray	Gravel	4′ 6″	36′	3″	2,000	,, ,,	1880
Millwall	Sand	4′	20′	3″	2,400	,, ,,	1884
Musselburgh	Gravel and Sand	8′	20′	3″	1,800	,, ,,	1886
New Ross	Gravel	5′ 6″	29′	3″	2,000	,, ,,	1885
Purfleet	Chalk	1′ 0″	70′	2″	1,600	,, ,,	1886
Rainham	Sand	14′	45′	2″	780	,, ,,	1899
Rotherhithe	Gravel	11′ 0″	26′	3″	1,560	,, ,,	1885
Swansea	,,	17′	29′	3″	1,500	,, ,,	1893
Widford	Chalk	4′	79′	2″	1,500	,, ,,	1890
Witham	Sand and Gravel	11′ 6″	18′	1¼″	480	,, ,,	1898
Wraysbury	Sand	7′ 6″	18′	2″	1,200	,, ,,	1891

	Twelve-Feet Tube with Hire of Plant and Man to Superintend Driving.	Add for each additional Foot.	Pump, Column, and Foundation.
$1\frac{1}{4}$-inch tube	£2 4 0	3s.	£2 10 0 to £3 10 0
2 ,,	3 10 0	4s. 6d.	,, ,,
3 ,,	7 10 0	10s.	£3 10 0 to £4 10 0
4 ,,	9 15 0	13s.	

To the above must be added the man's time in travelling, railway fares, carriage of materials, etc. A well recently driven in one of my districts to a depth of 17 feet, a 2-inch tube being used, cost £8 12s. 4d., the items being as under.

17-feet 2-inch tube well	£2 14 6
4-inch column, pump, and foundation .	3 8 0
Hire of man and plant	1 10 0
Man's time travelling	0 7 6
Railway fare and carriage . . .	0 12 4
Total	£8 12 4

The wages of the agricultural labourer who assisted in driving the tube is not included, but would not exceed 5s.

These prices may be compared with the following schedule of prices taken from Sir R. Rawlinson's *Suggestions as to the Preparations of Plans for Drainage and Water Supply* (Local Government Board, 1878).

Schedule of prices for sinking wells in Clay, lined with 9-inch brickwork in Portland Cement. Wooden curves, cylinders, and pumping extra.

4 feet diameter to depth of	200 feet,	50s.	per foot run
5 ,, ,,	200 ,,	65s.	,,
6 ,, ,,	200 ,,	85s.	,,
7 ,, ,,	200 ,,	105s.	,,

Rough estimate of well-sinking, through Clay, Chalk, and Gravel, entirely *exclusive* of brickwork or fittings.

Diameter of Well.	Depth.	Price per Foot of Depth.	Total Cost.
4 feet	50 feet	3s.	£7 10 0
5 ,,	50 ,,	4s. 6d.	11 5 0

Where hard rock has to be pierced or where the water-bearing stratum lies at a considerable depth below the ground surface, the well must either be excavated or bored. The cost of sinking as compared with boring is so excessive that nearly all deep wells are now bored. Not only is the cost much less, but as the bore-hole is lined with metal tubes (which should be of wrought iron, lap-welded and steel-socketed), surface springs are excluded, and the possibility of contamination reduced to a minimum. Various methods are employed and many different kinds of tools, according to the nature of the strata to be penetrated, and the depth and the manner of the borings, which vary from 3 to 18 inches in diameter; but in soft rock, like chalk, this diameter may be greatly exceeded. In the majority of cases the borings are made from the bottom of a dug well, the object usually being twofold: (*a*) to form a storage reservoir for the water; and (*b*) to provide a receptacle for the pumps. It is, however, found that in many cases the dug well can, with advantage, be dispensed with. It is only really necessary where the spring is weak and the demand for water intermittent. Such dug wells, unless very carefully constructed, also increase greatly the liability to contamination by surface water. During the process of boring a number of springs may be tapped, and the quality of the water yielded by each can be ascertained by analysis. If it be ultimately found that one of the upper springs yields the most suitable water, the tubes can be withdrawn and the hole plugged at such a depth

that only water from that particular spring is supplied. In the older wells the tubes lining the bore are usually not continuous, and water from divers sources has free access to the wells. In the more modern borings larger tubes are used for convenience in boring, and a smaller tube with tight joints is then inserted, reaching from the surface to the bottom of the well. The outer tubes may be afterwards withdrawn or the space between the two filled in with cement. With such a continuous tube the pump can be so attached that the water is drawn directly from the bottom of the well. The conditions which influence the yield of water from bored wells are so lucidly expressed by Mr. R. Sutcliff, in a paper read before the Brewers' Congress in 1886, that no apology is required for reproducing them here. "The continuous tube," says Mr. Sutcliff, "has an important bearing on the yield from the spring; the weight of the atmosphere being removed by the pump from the surface of the water in the tube well. This, as regards the velocity of the flow of the spring, is equivalent to drawing the water from some 34 or 35 feet lower than is possible when the weight of atmosphere presses on the surface of the water. The increase in supply under these conditions is equal to about 40 per cent., which acts as an important compensation for absence of storage. It may be interesting to give an example of this. A dug well, 25 feet deep and of 5 feet diameter, will hold 3,050 gallons of water. Suppose that such a well is supplied by a spring which, when the head of 25 feet is removed from it, will flow at the rate of 950 gallons per hour. As the maximum flow is only obtainable after the storage is completely exhausted, the average yield must be taken until that exhaustion occurs. Let the pumps be started to draw 1,500 gallons per hour, the quantity obtained by the storage will be exhausted in two hours. But as in that time the spring would have been yielding an average flow of, say, 700 gallons per hour, the

well would not be emptied until the pumps had been going about four hours. When that time had expired, the spring would be yielding its maximum of 950 gallons per hour, and the speed of the pumps would have to be slackened proportionately. Under these conditions, a total of 11,500 gallons would be drawn from the well in ten hours.

"Let a tube well be placed under exactly similar circumstances as regards supply and water level. The pumps drawing from a tube well could get 950 gallons per hour plus 40 per cent.; that is to say, 1,330 gallons per hour. Therefore, the tube well would in 10 hours yield 13,300 gallons—a gain, in that time, in spite of absence of storage, of 1,800 gallons; and the pumping from the tube well could be continued uniformly at the same speed for an indefinite period, so long as the spring maintained its flow.

"When the normal level of the spring is not sufficiently near the surface, or the flow is not rapid enough to enable an ordinary lift pump to draw the water, the tube well must be made of such size as will enable a deep well pump to be placed in it, as far below the surface of the water as may be necessary to obtain the required supply. A deep well pump can be placed 150 or even 200 feet below the surface; but when it becomes necessary to place it at that depth below the water level, the supply required is one that is very great compared with the spring that yields it. Because, although all springs increase until the base of them is reached, that augmentation is a constantly decreasing one. The reason for this decrease is obvious. The water flows through channels of fixed area. When the head of water is removed, the pressure is increased proportionately with the depth that the water is lowered; but the friction of passing through the channels also increases. So that to double the supply that flows at 150 feet below the head of the spring, it would be necessary to place the pump 600

feet under water. These facts are of the highest importance in deciding whether a given spring can meet the requirement of the consumer. Let it be supposed that two borings are made, and that springs are tapped by these borings, which both overflow the surface of the ground at the rate of 10 gallons per minute. To the casual observer both of these springs might be considered as equal. But one might be ten times stronger than the other. Let us call these springs A and B. The spring A, when we lower by pumping, gives no appreciable increase; whereas the spring B, when we lower it only 3 feet, yields double the quantity of water. Why is this? If it were possible to carry the pipes up from which spring A flows, we should find that the water would rise 100 feet before it came to rest; whereas with spring B, if we only piped it 1 foot higher, it would cease to flow. This would prove that spring A is a high-pressure one, the source of which is 99 feet above the ground level; but spring B has its source only about 1 foot above the ground level. The channels of communication in spring A are small, and the friction is depriving us of the advantage of the great head of water. The channels of communication from spring B are free and large. One may, however, be deceived unless the test of pumping is a prolonged one. What is known as a 'pocket of water' may appear from temporary pumping to be a spring of the B class; but sustained pumping will demonstrate the impostor, as the water level will not recover itself without a more or less prolonged period of rest. This proves that while the channels of communication are large, the area which is being drawn from is small. Under such circumstances a multiplication of wells would be of no advantage; but in many instances the friction of drawing water through the earth may be largely diminished by sinking a number of tubes and coupling them together, so that one pump draws from them. What is known as the 'cone of depression' is reduced by this method of drawing the

water. Tubes placed, say, 20 feet apart, may each only yield a small supply; but the aggregate obtained from a number of these tubes becomes very large.

"At the Burton Breweries, some forty or fifty 3-inch 'Abyssinian' tube wells yield 2,000,000 gallons daily; yet no one of the 3-inch tubes delivers more than 2,000 gallons per hour. The area from which they draw is so extended that at no one point is the water level materially depressed.

"At the Town Waterworks of Watford, a dug well of 10 feet diameter, supplied by a 12-inch boring at the bottom of it, proved inadequate when drawn from night and day to meet the requirements of the town. A single tube well of 8½ inches in diameter, placed some 30 feet from the dug well, doubled the supply of water obtainable, and thus enabled the hours of pumping to be materially reduced. Somewhat similar experiences were obtained at the Town Waterworks of Aldershot, Hertford, St. Albans, and Abbots Langley, all of which towns now derive their water supply from tube wells."

The imperfect construction of many of our older wells to some extent brought boring into disrepute. Thin sheet-iron was in many districts used for lining the bore. The imperfect joints very frequently admitted of the entrance of subsoil water, hence the water yielded was often polluted. In a comparatively few years the sides of the tubes corroded and collapsed, and the supply gradually, or, in some cases, suddenly failed. By the use of proper casing, such as the "Russian Brand" swelled and collar-joint casing, employed now so extensively, all these defects are obviated. The difficulty, however, of making these tubes absolutely water-tight is greater than at first would be anticipated, and where the slightest defect exists the continued raising of water by pumps fixed directly upon the bore tube is very likely to accentuate it by the continued lateral insuction of air and water. A most instructive example of such a defect is contained in Dr. Geo. Turner's *Report on the Water*

Supply to the Suffolk County Lunatic Asylum, previously referred to. Some years ago the prevalence of dysentery in this Asylum was attributed to the impure water supply, and a fresh supply was obtained from two bored wells, so constructed that contamination of the water appeared quite impossible. Dr. Turner says, "The construction of these bores is very similar in principle, but varies slightly in detail. In both instances an 8-inch steel pipe with screw joints was sunk into the chalk, the bore was then enlarged, filled with cement, and the 8-inch tube sunk into the cement, which was then allowed to set. After the cement had set, a 6-inch steel tube, also with screw joints, was passed through the cement to a distance of 200 feet, when the bore was again enlarged; the cavity was filled with cement, which was allowed to set, and then the boring was continued another 100 feet. The total depth of the bores was 305 and 350 feet respectively. The space between the 8-inch and 6-inch tubes was filled with cement through a composition pipe passed to the bottom, and the bore was fastened to the pump by an air-tight joint." Notwithstanding these elaborate precautions, dysentery again broke out in the Asylum, and was again traced to the water supply. Dr. Turner found that after continued pumping there was a marked difference in the quality of the water drawn from the two wells, and upon excavating around the tubes and pouring into the excavation a solution of chloride of lithium, he afterwards found distinct traces of this salt in the water drawn from the pumps. From the result of these and other experiments he concluded that there was no reasonable doubt that neither of the tubes was watertight. The danger of lateral insuction must be greater in wells in which the pump is screwed directly on to the lining tube, than in those in which the pump pipe or barrel is merely inserted within the lining tube, since the removal of the atmospheric pressure, in the former case, causes water or air to enter the bore through the most minute

apertures, and in course of time such apertures enlarge, admitting impurities more and more freely. This danger, in some degree, counterbalances the advantages of the increased supply, and it would appear to be safer not to directly connect the pump with the bore tube where water can be obtained in sufficient quantity without such attachment.

The cost of constructing bored wells varies with the nature of the strata which have to be pierced. Fifty years ago, local well-sinkers in Essex would pierce 300 feet of London clay, line the well, and fix a pump for a total cost of less than £100. At the present time similar wells cost about three times that amount, and the local well-sinker has disappeared. The only explanation appears to be that it has been found more economical to employ professional well-borers, and pay treble the price for a properly-constructed well, than to employ the local men. Sir R. Rawlinson, in his *Official Report to the Local Government Board on Water Supplies, etc.*, gives the following schedule of prices for making bore-holes in red sandstone. The prices for boring in chalk and in sand and clay average 1s. per foot less, but in sand and clay, where the boring exceeds 200 feet in depth, the price is, on the contrary, about 3s. per foot more than for boring in chalk or sandstone.

Diameter. Inches.	Per Foot Run.				Cost of Cast or Wrought-iron Pipes per Foot.
	First 100 Feet.	Second 100 Feet.	Third 100 Feet.	Fourth 100 Feet.	
3 or 4	5s. 6d.	7s. 6d.	11s. 6d.	14s. 6d.	4s. to 5s. 6d.
5	7s. 6d.	10s. 6d.	13s. 6d.	20s. 6d.	6s. 6d.
6	8s. 6d.	11s. 6d.	14s. 6d.	20s. 6d.	7s. 6d.
8	9s. 6d.	12s. 6d.	16s. 6d.	22s. 6d.	10s. 6d.
9	12s. 6d.	15s. 6d.	20s. 6d.	25s. 6d.	11s. 6d.
10	13s. 6d.	16s. 6d.	21s. 6d.	26s. 6d.	13s.
12	17s. 6d.	21s. 6d.	25s. 6d.	30s. 6d.	18s. 6d.

The following schedule of prices for borings from the surface from 3 to 12 inches in diameter, is exclusive of lining tubes but includes all labour and necessary plant. The prices quoted are per foot.

	Messrs. Le Grand and Sutcliff.		C. Isler and Co.	
	Boring in Alluvial and other Free-boring Strata.	In blowing Sand, Rock, Stone, and other hard or difficult Strata.	Gravel, Clay, Sand, or other soft Strata.	Rock or Stone.
Not exceeding 100 ft.	7s. to 14s.	15s. to 50s.	8s. to 20s.	20s. to 40s.
,, 200 ft.	12s. to 24s.	20s. to 70s.	13s. to 30s.	25s. to 50s.
,, 300 ft.	16s. to 30s.	25s. to 70s.	18s. to 40s.	30s. to 60s.
,, 400 ft.	20s. to 40s.	30s. to 80s.	23s. to 50s.	35s. to 70s.
,, 500 ft.	30s. to 50s.	35s. to 90s.	28s. to 60s.	40s. to 80s.

The wrought-iron, lap-welded, steel-socketed tubes vary in price with the fluctuations of the market, but the following are recent estimates:—

3-inch	internal diameter,	$\frac{1}{4}$	inch thick,	4s.		per foot
4	,, ,,	,,	,,	5s.		,,
6	,, ,,	$\frac{5}{16}$	,,	9s. to 10s.		,,
$7\frac{1}{4}$	,, ,,	,,	,,	11s. to 13s.		,,
$8\frac{1}{2}$-inch	diameter and	$\frac{5}{16}$	inch thick,	15s. to 17s.		,,
10	,,	,,	,,	18s. to 20s.		,,
$11\frac{1}{2}$	,,	$\frac{3}{8}$	,,	23s. to 25s.		,,

The approximate depth at which water may be reasonably expected to be found, and the nature of the strata to be penetrated, being known, the cost of constructing a bored well can be ascertained from the above data. An estimate of the amount of water which the well will yield can only be given by those who have made a special study of the hydrology of the district.

The tables on pp. 383-4 give the details of a number of

typical wells bored during recent years by Messrs. Le Grand and Sutcliff.

As the temperature of the earth's crust increases as we descend, it follows that water taken from a great depth must have a higher temperature than water from shallower wells. The increase in temperature has been found to vary somewhat considerably in different localities, but 1° F. for every 50 feet to 60 feet descended is a fair average. A well 1,000 feet deep, therefore, may be expected to yield a water having a temperature 16° to 20° higher than that of the subsoil water in the same locality, so warm in fact as to be decidedly unpalatable. In some countries the water obtained is quite hot. Thus, in Queensland, some of the recently sunk deep bores yield waters having a temperature of from 162° to 175° F., the average of a number of wells being over 100° F.

In all cases, before deciding upon boring for water, an expert hydro-geologist should be consulted, otherwise the experiment may prove a costly failure. Even the most experienced expert may at times be at fault. Neither the quality nor the quantity of water obtainable can be invariably predicted. The supply obtainable may be increased in various ways. By driving two or more tubes, and connecting the various wells to a main leading to the pump, the area drawn from is increased. This, however, seriously augments the expense, and unfortunately is not always successful. Thus, at Liverpool, where sixteen bores had been made from the bottom of one well, Mr. Stephenson found that the yield of the whole was 1,034,000 gallons per day, whilst from a single bore-hole, the other fifteen being plugged, the yield was 921,000 gallons. In this case, of course, the bores were much too near together. By placing the pump barrel at a greater depth in the well, more water may be obtained. In London the long barrel-pumps are fixed at depths varying from 200 to 300 feet. The usual plan is to place them about 50 feet

TABLE XI.

ARTESIAN BORED TUBE WELLS.

Locality.	Water-bearing Stratum.	Water Level from Surface.	Boring Depth from Surface.	Diameter of Bore.*	Constant Yield per Hour.	Date.
Abbots Langley	Chalk	5′ 6″ below	1 × 150 ft.	6 in.	16,000	1886
Aldershot	,,	12′ ,,	7 × 250′/350′	6″/10″	70,000	1880/1894
Alnwick	Sandstone	overflows 30′ above surface	1 × 158 ft.	6 in.	4,000 at surface	1886
Cirencester	Forest Marble	6′ below	1 × 129 ,,	4	4,000	1880
Hertford	Chalk	8′ ,,	1 × 100 ,, 1 × 81 ,,	8½ ,, 7¼ ,,	24,000	1884 1888
St. Albans	,,	1′ 4″ ,,	1 × 150 ,,	7¼ ,,	20,000	1886
Wallingford	Lower Greensand	5′ 9″ ,,	1 × 55 ,,	7¼ ,,	6,000	1884
Watford	Chalk	11′ 6″ ,,	1 × 150 ,,	8½ ,,	30,000	1881
West Worthing	,,	8′ ,,	1 × 100 ,,	8½ ,,	12,000	1887
Wimborne	,,	overflows 2′ above and delivers 60 galls. per minute at surface.	1 × 130 ,,	7¼ ,,	10,000 by pumping	1889
Kingsheath Brewery	Keuper Marl	156 ft. below	1 × 1,106 ,,	4 ,,	1,100 by deep well pump	1888
Southampton	Chalk	18′ ,,	2 × 100 ,,	6 ,,	200,000	1886
* Stockport	New Red Sandstone	,,	1 × 348 ,,	12 ,,	2,000	
* Patricroft	,,	,,	1 × 292 ,,	12 ,,	4,000	
* Warrington	,,	,,	1 × 212 ,,	18 ,,	20,000	
* Cardiff, S. Wales	,,	,,	1 × 248 ,,	18 ,,	30,000	

* These wells were bored by Messrs. Mather and Platt of Salford (Bailey Denton, *Sanitary Engineering*, p. 113).

TABLE XII.

OTHER ARTESIAN OR BORED DEEP-WELLS.

Locality.	Water-bearing Stratum.	Depth of Bore in Feet.	No. and Diameter of Bore.	Yield per Hour in Gallons.
Various London Wells	Tertiary Sands	...	Single	1,800 to 7,200
Sleaford—Bass & Co.'s	Lower Oolite	172	...	12,000
Bourn Public Supply	,,	120	5 in.	34,000
Long Eaton Public Supply	Millstone Grit	370	2×10 in.	37,500
Aston Public Supply	New Red Sandstone	400	Single	125,000
Eaton Hall	,,	350	6 in.	12.000
Chatham Dockyard	Chalk	290	12 in.	60,000
Woolwich	,,	580	Single	60,000
London Orphan Asylum	,,	257	,,	3,400
Colne Valley	,,	140-480	Single, 6 to 10 in.	1,700-30,000
Uxbridge—Mercer's Mill Brewery	?	130	4 in.	4,200 overflows
Le Chapelle, Paris	Chalk	2,400	...	536,000

ARTESIAN BORED TUBE WELLS.

Locality.	Water-bearing Stratum.	Water Level.	Boring Depth from Surface.	Diameter.	Constant Yield per Hour in Gallons.	Date.
Slough	Chalk	6 ft. 10 in. below	3-139 & 166	$11\frac{1}{2}$ in.	100,000	1896
Gosport	Bagshots	21 ft. 6 in. below	1-1200	$7\frac{1}{4}$ in.	1,200	1897
Havant	Chalk and Flints	Overflows	1-118	$11\frac{1}{2}$ in.	30,000	1898
Southampton	Bagshots	Overflows	1-295	$8\frac{1}{2}$ in.	1,600	1897
Tunbridge Wells	Ashdown Sands	24 ft. below	1-603	6 in.	4,800	1895
Sleaford	Lincolnshire Limestone	Overflows	2-151 & 177	6 in.	50,000	1897

below the water level, so that pumping may go on continuously, if necessary, until the head of water has been reduced about 80 feet. Recently most successful attempts have been made to increase the flow through closely-jointed rocks, by exploding a charge of dynamite or blasting gelatine at the bottom of the well. The explosion shatters the surrounding rock and opens out the fissures through which the water pours. At Rochester a well had been sunk to a depth of over 300 feet without finding water. Messrs. Isler and Company placed a charge of gelatine, weighing 18 lb., at a depth of 307 feet, and exploded it. The result was an abundant supply of water, the well yielding afterwards some 20,000 gallons per hour. The proportion of unsuccessful borings in England is probably very inconsiderable, but no data are available upon which to base a reliable estimate. In several of our colonies, where well-sinking is being undertaken by the respective governments, some interesting information on this and other points is given in the engineers' reports. The following brief account of the results of boring operations in our colonies is compiled from various blue-books issued during recent years by the respective governments.

Queensland.—During the last few years many wells have been bored by the Government under the supervision of the official hydraulic engineer. The number of successful bores during the past eight years (1892-1900) appears to be 424, and the cost about £1,000,000. Three hundred of these wells overflow, yielding over 190 million gallons of water daily. All the borings made have not been successful; in some instances no water was found, in others the water was not fit for domestic purposes, and some bores were abandoned for other reasons. The chief wells are:—

District..	Depth.	Yield per Day.	Temp. of Water.	Cost.
Barcaldine .	691 ft.	175,000 galls	102° F.	£1,340
Blackall .	1,663 ,,	300,000 ,,	119° F.	5,074
Charleville .	1,571 ,,	3,000,000 ,,	106° F.	3,525
Cunnamulla	1,402 ,,	540,000 ,,	106° F.	2,316
Muckadilla .	3,262 ,,	23,000 ,,	124° F.	7,382
"65-mile bore'	2,362 ,,	104,000 ,,		3,073

About 715 public and private wells have been sunk, varying in depth from 86 to 2,484 feet. The number of unsuccessful borings is not stated. The water is derived from the lower cretaceous formation, and most of the wells overflow. The largest yield is from a private bore in the Warrego district. The well is 1,502 feet deep, and yields 3,500,000 gallons of water daily (112° F.), at a pressure of 200 lb. to the square inch. The yield at the present time from all the wells is estimated at over 200,000,000 gallons per day. The flow of a large proportion is uncontrolled, and most of it wasted. A bill was recently introduced to regulate the flow from these bores and prevent the lowering of the pressure (water level), but it was thrown out by the Upper House. Regulating valves are used for all the Government bores.

In *South Australia* it is estimated that the area of the water-bearing chalk basin is nearly 100,000 square miles; but the number of wells bored at present is inconsiderable Water has been obtained at depths varying from 237 to 1,220 feet, the temperature ranging from 81° F. to 90° F., and the yield from 48,000 to 1,200,000 gallons daily. In some wells the water rises considerably above the surface; in others it does not reach the outlet of the bore.

In the *Colony of Victoria* the Government has expended some £50,000 in making experimental bores, but apparently with little success. In some cases the rocks were pierced to a depth of over 2,000 feet without water being discovered; in others the water obtained was unfit for domestic

purposes, whilst in the few successful bores the water level was far below the ground surface and the supply limited. One instance is recorded in which the saline constituents of the water acted so powerfully upon the iron lining of the bore as to destroy its continuity within eighteen months.

New South Wales.—In 1892 Mr. Boultbee, the Officer-in-Charge for Water Conservation, issued a report on Artesian boring, containing sections and descriptions of all the Government bores. The bores when decided upon are let by tender, the work being done under official supervision. Mr. Boultbee gives a list of twelve completed borings, and refers to 40 other bores in progress. Particulars are also given of forty-five private bores. The wells vary in depth from 53 to 2,000 feet. Two borings appear to have been unsuccessful; the remainder yield from 24,000 to 2,000,000 gallons of water per day. Most of the private wells are from 700 to 1,000 feet deep, and the flow varies from nil to 1,728,000 gallons daily. The tenders for the Government bores varied from 24s. to 27s. per foot for the first 1,000 feet; from 27s. 6d. to 32s. 6d. for the next 500 feet, and from 30s. to 40s. for an additional 500 feet, exclusive of casing. The contractor finds all plant, tools, labour, etc., but the Government does all the carting and supplies the casing. The average cost of the bores per foot, including casing, is said to be 37s. All the Government bores, and some of the private bores, have valve arrangements for regulating the flow, but Mr. Boultbee believes that some 16,000,000 gallons of Artesian well water runs daily to waste, and he recommends legislation to prevent this. Imperfect casing is also probably the cause of serious waste, and this he thinks should be dealt with by legislation, as is already done in some of the North American States. The chalk basin yielding water is estimated to have an area of 40,000 square miles. Over the catchment area supplying this basin the average rainfall is 22 inches, and only about $1\frac{1}{2}$ per cent. of this finds its way into the rivers. It

is assumed, therefore, that 50 per cent. of the total rainfall percolates and is recoverable by means of wells and bores. As the catchment area is only about 13,000 square miles in extent, the water from the bores should not be sufficient to irrigate more than about one-sixth the area of the chalk basin. Mr. Boultbee believes that if further operations are equally successful, it will be "difficult to estimate the progress and prosperity that must naturally ensue." The few analyses given show that some of the wells yield strongly saline water, and others, water which is strongly alkaline, such as is derived from the chalk in certain portions of Essex. The Government Veterinarian, reporting on saline waters, says, "It is easy to understand that starving, or even thirsty travelling stock may suffer disastrously from drinking at once a large quantity of water containing a high percentage of saline material. Horses and cattle will drink from 5 to 12 gallons a day, sheep from 1 to 2 gallons a day. Drovers should be cautioned at saline drinking-places of the danger of permitting stock to drink too freely, until they have become accustomed to the medicinal properties of the water."

Cape of Good Hope.—The Government Inspector of Water Drills, in his report for 1893, says that the work undertaken by the Government has been an unqualified success, but the geological formation in many parts of the colony is such as not to be "conducive to the existence of Artesian areas of any great extent. A great portion of the colony, known as the Karoo, however, contains many such areas, and here prospecting for water has been most successful. This district is composed of a series of areas formed by a network of intrusive igneous dykes, chiefly of a dolerite nature, cutting through the sandstone and shales and acting as intercepting barriers to the underground water. Since the commencement of operations in May, 1891, out of a total of 341 holes bored, water was

tapped in 289 and overflowed from 128. The average depth was only 43 feet per hole, and the deepest bore was only 227 feet. The flow from the 128 bore-holes is estimated at 2,332,000 gallons daily, or an average of about 18,000 gallons per well. In several cases the flow has decreased; in others it has increased. The Inspector thinks that there is little fear of exhausting the underground reservoirs, since moderate-sized towns, such as Colesburg, Victoria West, Hanover, Veuterstad, and Bristown, "boast of perennial streams, issuing from one or two bore-holes in each case, sufficient to supply their domestic wants as well as to irrigate numerous erven." The Inspector recommends that where the water does not overflow, 4-inch bores should be made instead of 2-inch as at present, and to such a depth as will ensure a 50-feet head of water from which to pump. With a deep-well pump and windmill, practically inexhaustible supplies could be obtained from such wells at a nominal cost. A few very deep wells have been bored (up to 1,200 feet), but the results are not encouraging. In Bushmanland and Bechuanaland, where the general geological formation is gneiss and granite, the rock can only be pierced by the diamond drill, and the wear and tear of the diamonds is severe. As the water lies in the rock fissures at but a slight depth, the rock is better penetrated by means of blasting.

In the *United States* a special Department at Washington collects information with reference to all wells bored, and in several states Acts have been passed to encourage the sinking of Artesian wells, and for preventing waste of the water flowing therefrom. The number of such wells is simply enormous. In the Utah Territory there are nearly 2,000; in the San Joaquin Valley, California, about 3,000; in the San Louis Valley, 2,000; in Deseret, 2,000, etc. In Kern County, California, within an area of 18 by 14 miles, there is a group of wells yielding 61,000,000 gallons of water daily. To the development of well-boring

the reclamation of the Great American Desert is in great part due. Enormous tracts of land, over which the annual rainfall is only from 2 to 6 inches, are now irrigated by the water overflowing from Artesian wells.

In *Algeria and Sahara* the French engineers have during recent years been engaged in reclaiming the deserts by means of water derived from deep bores, and it is stated that the flow from the wells already sunk is about 100,000,000 gallons daily, and that the effect produced upon the sandhills by irrigation is amazing.

In *Argentina and Uruguay* a drilling company has recently sunk a number of wells, and last year the Buenos Ayres and Rosario Railway Company drove an Abyssinian tube well to a depth of 200 feet, and obtained an abundant supply of water.

In arid regions, and where the rainfall is fitful, water can often be obtained for irrigation purposes by boring, and it is probable, now that increased attention is being drawn to this method of obtaining water, many districts at present uninhabitable will become both populous and prosperous. In certain of our Colonies it may safely be asserted that the discovery of these subterranean sources of water will ultimately conduce to far greater prosperity than the discovery of gold.

In all attempts to obtain water by sinking wells, the following facts should be borne in mind. Sand or gravel resting on chalk will yield no water, unless the chalk also is penetrated to below the plane of saturation; that chalk contains immense volumes of water, but almost exclusively in the fissures. Wells or borings sunk in very solid chalk may yield no water, the more fissured the stratum and the greater the yield that may be anticipated. The tertiary sands between the London clay and the chalk yield only a moderate quantity of water. The impermeable beds of Purbeck and Portland stone often contain a considerable amount of water in their fissures, but under the latter rock

water may be found in the porous stratum between it and the clay beneath. Limestone is only slightly porous, and the water contained therein is probably chiefly found in the fissures. The lower oolite contains large quantities of water held up by the impervious beds of the lias. In the magnesian limestone water is only found where fissures are struck, but in this and the mountain limestone the water may be very abundant. In fissures of the metamorphic rocks, water also may be met with in the fissures if the sinking or boring is fortunate enough to strike such; but as the stratification is usually very irregular, the result of a boring can never be with safety predicted.

CHAPTER XXI.

PUMPS AND PUMPING MACHINERY.

Numerous varieties of pumps are now manufactured for raising water, and each probably possesses some advantages over the others under certain conditions. A pump which under one set of circumstances will work effectively and economically, may under other circumstances be ineffective or extravagant. Where large quantities of water have to be raised, the selection of a pump is of the highest importance, and it is only when the duty which it will have to perform and the exact conditions under which it must work are fully known that the selection can be satisfactorily made. All the varieties in ordinary use can be classified under the four following types—(*a*) Lifting pumps, (*b*) Plunger or force pumps, (*c*) Centrifugal pumps, and (*d*) Air Lift pumps.

(*a*) The commonest form of pump, the atmospheric, is the simplest form of this type. The essential part is the barrel, which is truly cylindrical and carefully bored and closed at the bottom by a valve opening upwards. Within the barrel works a piston or bucket, fitting the cylinder accurately, which is also provided with a valve opening upwards. When the piston ascends, the atmospheric pressure is removed from the surface of the lower valve, and water ascends through the so-called suction pipe, ultimately entering the pump barrel. When the piston descends the lower valve closes, and the water is forced through the valve in the piston, and at the next up-stroke

is discharged from the pump. The height at which the pump barrel may be fixed above the surface of the water to be raised obviously depends chiefly upon the atmospheric pressure. At sea-level this corresponds to a column of water about 34 feet high. As the valves and piston, even with best workmanship, are not perfect, such a pump cannot be depended upon to raise the water more than 27 feet. The vertical distance between the level of the water to be raised and the highest point reached by the piston must not, therefore, exceed this distance. Where the water-level fluctuates care must be taken to measure from the lowest level reached during these fluctuations, otherwise the water may at times fall so low that the pump will cease to act. This form of pump is only suitable for hand power and for use where it is not inconvenient to raise the water as required. For shallow wells it is almost universally employed, the water discharged from the pump barrel passing directly or through a very small reservoir to the outlet. In another form the upper portion of the body of the pump is elongated, or a pipe is connected therewith, into which the water rises with every stroke of the piston. As each stroke not only has to overcome the atmospheric pressure, but has also to raise this column of water, it is evident that the height to which water can be so raised by hand power is limited. About 30 feet is the highest to which water can be conveniently raised by one man. When other motive power is employed it may be raised by such a pump to about 100 feet above its source. This limit, in actual practice, is probably due to several causes, of which the principal is the uncertain action of the piston valve under such great pressure. In deep wells, where the water-level is more than 24 or 25 feet from the surface of the ground, the pump must be fixed within the well, the piston rod being lengthened so as to be connected with a lever or handle, or to a fly-wheel. In such cases it is usual to fix a double-barrel pump, since it is easier to raise a given

volume of water with such a pump than with a single-barrel of capacity equal to the two together. With the double-barrel the work is distributed, each half-turn raising one piston, whereas, with the single-barrel the whole lift is on one half turn. With a treble pump the work is still more equally distributed; but as complications are introduced the double-barrel is generally preferred.

The pump need not be fixed over or even near the well; but if at any considerable distance, it must be remembered that a certain amount of friction is introduced, and must be allowed for. The suction pipe must fall all the way from the pump to the well, otherwise air may lodge in the bends and impair the action of the pump. In long suction pipes it is desirable to have a foot valve to retain the water when the pump is not in use, and to prevent the concussion caused by the sudden arrest of the motion of the long column of water at each down-stroke of the piston; a vacuum vessel also should be connected with the pipe just before it enters the pump.

In another form of lift pump a solid piston plays in a barrel placed alongside a second barrel, which is closed at each end by a valve opening upwards. The upper end of this second cylinder is continuous with the rising main, whilst the lower end is continued into the suction pipe. The upper end of the pump barrel is connected by a wide tube with the valve cylinder. When the pump is in action depression of the piston causes a vacuum in the barrel within which it works, into which water rises through the valve at the upper end of the suction pipe. When the piston is raised this water is forced through the upper valve into the rising main. A pump of this character can raise water a height of 700 feet and upwards.

(*b*) In the plunger or force pump a solid plunger takes the place of the ordinary piston or bucket, but the suction pipe, valves, and rising main resemble in arrangement the pump just described. The cylinder, however, in which the

plunger works is connected with the valve box by an opening near its base, and the plunger does not accurately fit the cylinder in which it works. When pumping is in operation the water rises in the suction pipe to fill the vacuum produced by the rising plunger, and when this falls it forces into the rising main an amount of water equal to the volume of the plunger which enters the cylinder. This single-acting plunger pump is largely employed for raising water to considerable heights. It is obvious that in this form of pump also the vertical length of the suction pipe must not exceed 27 feet. As a matter of practice the pump barrel is usually only a few feet above the surface of the water to be raised. Two or three such pumps may be combined, and so arranged that the discharge, instead of being intermittent, as in the single-barrel pump, becomes practically continuous. For high lifts and heavy pressures air chambers must be connected with these pumps. The water being forced into these instead of directly into the main, the compressed air acts as a cushion, and tends greatly to equalise the flow of water and relieve the valves from undue shock. The force pump is less troublesome to keep in repair than the lift pump, since it dispenses with the bucket, the clack valve of which can only be reached for repairs by taking the pump to pieces. Whilst the pump barrels are usually fixed vertically, they are occasionally placed in a horizontal position. In waterworks where water has to be raised from a well, and then forced to a considerable elevation, usually two sets of pumps are employed, one raising the water from the well to a reservoir at or near the ground-level, and the other forcing the water from this reservoir to the highest point at which the water is required.

(*a* and *b*) The so-called bucket and plunger pump, which is probably most extensively used for high lifts, combines in its construction both principles *a* and *b*, acting both as a lift and plunger pump. The piston rod working within

the pump barrel has a cross section half that of the bucket or cylinder, otherwise in construction it resembles the ordinary lift pump. When in action the down-stroke of the piston forces the water through the bucket valve; but as half the volume of the cylinder is occupied by the piston, half the water is forced into the rising main. With the up-stroke the other half passes into the main, whilst the barrel under the piston is again filling from the suction pipe. It is practically, therefore, a double-action pump, performing with one set of valves the work of two smaller pumps.

Other combinations of these two classes of pump are made, each manufacturer claiming some advantage for his special construction.

The Glenfield Company, of Kilmarnock, have recently introduced a pump invented by Mr. Henry Ashley, in which there is no bottom clack, the suction and delivery valves both being in the bucket. The advantages of this pump are greater accessibility to the working parts, an important matter in deep wells, and quicker running, allowing of smaller pumps being used. These pumps are being used at the Brighton Corporation Waterworks and at the East London Waterworks.

(c) *Centrifugal Pumps.*—These pumps differ entirely from either of the types just described, inasmuch as they contain no valves or pistons. A series of fans or blades are attached to a spindle, passing through the centre of a cast-iron case in which they are contained. By the revolution of these fans a partial vacuum is produced behind, into which the water is drawn, or rather forced by the pressure of the atmosphere, whilst the water in front of the blades is forced into the rising main. The efficiency of such pumps depends chiefly upon the degree to which fluid friction and shock, from impact of the blades upon the water, can be reduced, and these again depend upon the mode in which the water enters the pump, and upon

the curvature and arrangement of the blades. These pumps are not suitable for raising water to any considerable height. Up to about 25 feet they are probably more effective than any other form of pump, but above 30 feet a good plunger pump will give better results. Centrifugal pumps are made capable of raising water over 100 feet, and as they are more simple and compact than other types, these advantages may, under certain circumstances, more than compensate for the larger amount of fuel consumed when water has to be raised more than 30 feet. The advantages of this type as compared with either of the preceding may be summarised as under:—

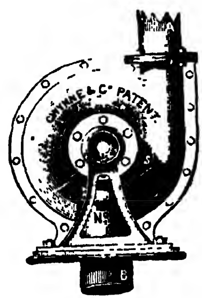

FIG. 21.—Centrifugal Pump. A, rising main; B, suction pipe.

1. There being no vibration or oscillation, a lighter and less expensive foundation is required.
2. They are more easily and readily fixed and repaired.
3. Greater simplicity of construction, and greater durability from the absence of valves, eccentrics, air-vessels, etc.
4. Less affected by sand or grit.
5. Moderate cost, and up to a certain point the greater efficiency measured by (*a*) the power employed, (*b*) the quantity of water raised, (*c*) the height to which it is raised, and (*d*) the time required to raise it.

(*d*) From America we have had introduced the Air Lift

Pump, which has certain advantages for deep well work, especially where sand is raised in the water. There are no valves or mechanical parts of any kind. The pump consists of a water pipe and an air pipe, the latter discharging compressed air into the former at its bottom. The air rises in the water pipe, carrying the water with it in short detached columns. Compressed air for pumping purposes is largely used in America, and several installations have recently been made in this country.

Another very useful pump where the water has only to be lifted a few feet is the "Pulsometer." This pump contains neither bucket nor plunger, the vacuum into which the water rises by air pressure being produced by the condensation of steam.

Theoretically the amount of water raised by a lift pump in a given time depends upon the diameter of the pump cylinder, the length of the stroke of the piston, and the number of strokes, whilst in the plunger type the diameter of the plunger must be substituted for that of the cylinder. For convenience of calculation the following table gives the amount of water in gallons delivered per inch of stroke in pumps with cylinders or plungers of various diameters:—

Diameter of Cylinder or Plunger.	Gallons of Water delivered per each Inch of Stroke of Pump.
$2\frac{1}{2}$ inches	·0176
$2\frac{3}{4}$,,	·0212
3 ,,	·0254
$3\frac{1}{4}$,,	·0298
$3\frac{1}{2}$,,	·0398
4 ,,	·0454
5 ,,	·0708
6 ,,	·1020
8 ,,	·1816
12 ,,	·4080

To find the theoretical quantity of water raised per minute by a given pump, multiply the quantity delivered per inch stroke corresponding with the diameter of the cylinder or plunger by the length of the stroke and the number of strokes per minute. For example, a pump with 4-inch cylinder, 10-inch stroke, and working at 30 strokes per minute, should deliver

$$\cdot 0454 \times 10 \times 30 = 13\cdot 62 \text{ gallons per minute.}$$

If such a pump actually delivered this amount of water its action would be perfect, and its modulus of efficiency would be considered as 100. In actual practice such an efficiency is never reached. The common lift pump has usually only an efficiency of about 50; ordinary plunger pumps of from 60 to 70, whilst the highest class of waterwork pump often does not exceed 80. The efficiency of centrifugal pumps varies widely with the conditions under which they are used, and under favourable circumstances may not exceed 50 per cent. of the theoretical amount.

The degree of efficiency attained is an index of the quality of the machine turned out by the maker; but it varies with the construction of the pump, and one form may show a higher efficiency when working at a certain speed and doing a certain duty, whilst another may excel it at a different speed and duty. Unnecessary friction is introduced and efficiency impaired if the suction and delivery pipes be too small, or have sharp bends along their course. The delivery pipe should have a diameter at least half that of the pump barrel, and the suction pipe should be still wider. In the latter the atmospheric pressure alone has to raise the water against the force of gravity and has to overcome the friction, whereas in the former these are effected by the power used to work the pump.

Water may be raised by means of pumps by manual labour, by labour of some animal, horse, pony, ox, mule or ass, by aid of the wind or falling water, or by steam,

hot-air, gas, or oil engines. Electrical pumps also are now in use.

For small and intermittent supplies, where the water has only to be raised to an inconsiderable height, human labour must often be depended upon; but both human and animal labour is often used when wind or water power could be profitably utilised, and even where some form of gas or oil engine would be more economical.

Hand labour may be employed in pumping, either in working a pump handle or in the continuous turning of a crank and handle. In the ordinary pump the leverage is usually about 6 to 1, *i.e.*, the distance from the fulcrum to the free end of the handle is about six times that of the fulcrum to the point of attachment of the handle to the piston rod. With a crank and handle the leverage varies from 3 to 1 to 4 to 1, according to the length of the stroke and the diameter of the circle described by the handle. Whilst the latter is pleasanter to work, it is evident that a man exercises more power with the former. With the pump, the whole or nearly the whole of the force is exerted in depressing the handle, whereas with a crank and fly-wheel the work is more equalised. With a single-barrel pump the pump handle or the fly-wheel can be so weighted as to render the work in the up-stroke and down-stroke more nearly equal. If the well frame be provided with a wheel and pinion the power required to raise water a given distance can be diminished in any ratio; but the amount of water raised by each revolution of the handle is diminished in the same proportion, or, in other words, what is gained in power is lost in time. It is easier to raise a given quantity of water with a double-barrel pump than with a single-barrel pump of a capacity equal to the two barrels, since with the former half the water is raised with each half turn, whereas, with the latter the whole is raised at one half turn.

The resistance to be overcome in raising water any given

height will be the weight of a column of water of that height and of cross section equal to that of the pump piston, plus the resistance due to friction and the weight of the pump rods. The following table admits of the water pressure being readily calculated:—

Diameter of Pump Cylinder.	Weight of Corresponding Column of Water 10 Feet High.
2 inches	13·6 lb.
2½ "	21·2 "
3 "	30·6 "
3½ "	41·6 "
4 "	54·4 "
5 "	85·0 "
6 "	122·4 "

Example.—Required the water pressure upon a piston of 3 inches diameter raising water to a height of 80 feet. Since from the table a column of water 3 inches in diameter and 10 feet long weighs 30.6 lb., the pressure of a column 80 feet long will be 244.8 lb. The above weight includes that of the column of water raised by the atmospheric pressure, since the piston is raised against this pressure. With an ordinary pump, having a handle with leverage of 6 to 1, a force of $\frac{244.8}{6} = 40.8$ lb. would have to be applied to raise the water alone without allowing for friction, etc. By the use of a wheel and pinion this power could be reduced so as to enable one man to raise the water, the power which an ordinary labourer is able continuously to employ for such a purpose being only 25 lb. From the above table the height to which one or more men can raise water by means of a pump worked either by a handle or crank can be determined approximately, if the effect due to friction be not excessive.

The following table, by Molesworth, gives the theoretical power required to raise water from deep wells, or to raise water a given height. In using it an allowance must be

made for friction in the gearing and pipes, for it should be remembered that the fluid friction of water traversing a pipe varies directly as the length of the pipe and as the square of the velocity. Doubling the length of a pipe therefore will double the friction, whereas, diminishing the internal area by half will increase it four-fold :—

Quantity of Water raised per Hour.	Maximum Height to which Water can be raised.			
	By one Man turning a Crank.	By one Donkey working a Gin.	By one Horse working a Gin.	By one Horse-power Engine.
Gallons.	Feet.	Feet.	Feet.	Feet.
225	80	160	560	880
360	50	100	350	550
520	35	70	245	385
700	25	50	175	275
900	20	40	140	220

It is assumed that a good class double or treble-barrel pump is used.

Wind as a motive power for driving pumps is again receiving considerable attention in consequence of the introduction of improvements rendering the wind engine more reliable, more uniform in action, less liable to damage by storms, etc. For pumping water to supply farms, groups of cottages, and mansions, the wind can often be utilised. Beyond the first cost of the engine there is practically no expense, and in the most modern mills self-regulating gearing reduces the personal attention required to a minimum. Naturally they are most efficient in exposed situations, but they can be utilised anywhere if placed at such an elevation as to receive the full force of any wind which blows. The mill will work from 30 to 35 per cent. of the possible time, but to provide for the periods of calm it is necessary to have the mill amply large and a storage reservoir capable of holding from four to seven days' supply

of water. Unless these precautions are taken in the first instance, occasional failures in the supply are certain to occur, necessitating the provision of a steam or other engine, or gearing for animal power, to work the pumps during the intervals of calm.

The wind engine may be fitted with a crank, to which the piston rod of the pump is directly attached. This form, however, is only adapted for raising very limited supplies of water; for larger quantities, or where the water has to be drawn from a considerable depth or forced to a height, it is better to connect with gearing from which a double or treble-barrel pump can be worked. Mills with annular sails are now almost exclusively employed for pumping purposes, and the sails may be either "solid" or "sectional." In the "solid" form each sail is pivoted at both ends, and coupled together with rods, and so adjusted as to develop the maximum of power when working. An automatic regulator causes the sails to furl when the wind pressure becomes too high, and so ensures the safety of the mill. The head also revolves, and is kept facing the wind either by a large tail vane or a tail-steering wheel. By aid of levers the engine can be started or stopped and its speed regulated. In the "sectional" wheel the individual sails are not pivoted into any framework, but are fixed at a definite angle and connected together into a series of sections which vary in number with the size of the wheel. Each section carries a weight or counterpoise so hung that when the wind is very high the wheel opens and assumes a tubular form, allowing the wind to pass through. When the wind falls the sails resume their normal position and the mill is again in action. It is claimed that this form is safer in a storm, is more easily regulated to work at a uniform speed, and is more sensitive to light breezes. Either form can be fitted with an automatic appliance for keeping the water in the supply tank or reservoir at a definite height. Where water has

only to be raised a few feet, the wind engine may work an Archimedean screw, or a dash wheel, or a "Noria" pump (an endless chain carrying a series of small buckets), instead of the ordinary force or lift pump. Such contrivances, however, are only adapted for raising water for irrigation and similar purposes.

The amount of power developed by these engines varies with the diameter of the wheel, its construction, and the velocity of the wind. If built on correct principles the wind will produce the same effect upon the wheel of one maker as upon another, but a difference may arise from loss of power by friction, leverage, gearage, etc. Where the mill has to be fixed at some distance from the pumps, the transmission of the power causes further loss. Whilst some makers claim that, with a wind of 18 miles an hour, their machines, with wheel of 13 feet diameter, have 2 horse-power, other makers, more modest, claim only to give 1 horse-power with such a wheel. Roughly stated, the power of a wind engine varies directly as the square of the diameter of the wheel, that is, a 20-foot wheel will do twice the work of one 15 feet, and four times that of one 10 feet in diameter. As an approximate guide to the amount of water which a wind engine of modern construction will raise, the following estimates may be useful. The water raised is given in gallons per hour, and the wind is assumed to be blowing at a rate of from 14 to 18 miles an hour. It must also be remembered that the average day's work corresponds to about eight hours.

	Diameter of Sail.	Quantity raised per Hour.	Height raised.	Daily Supply.
	Feet.	Gallons.	Feet.	Gallons.
Maker A.	10	200	100	1,600
,,	12	250	150	2,000
Maker B.	10	250	100	2,000
,,	12	250	150	2,000
,,	12	400	100	3,200
Maker C.	10	240	50	1,920
,,	12	240	100	1,920
Maker D.	10	210 to 300	100	1,680 to 2,400
,,	10	300 to 450	50 to 60	2,400 to 3,600
,,	12	300 to 500	100	2,400 to 4,000
,,	30	7,000?	150	...

Expressed in terms of h.-p., a 10-foot mill will give ½-1 h.-p., a 12-foot mill 1-1½ h.-p., a 14-foot mill 1½-2 h.-p., a 16-foot mill 2-2½ h.-p., an 18-foot mill 2½-3 h.-p., and a 20-foot mill 3-4 h.-p.

Estimates by different makers for pumping engines of various kinds can readily be obtained, but in considering those for wind engines it must be remembered that the storage capacity required is much larger than with any other form of engine, and therefore increases the initial expense. Where a larger supply than 20,000 gallons per day is required, a steam or gas engine is probably in all cases preferable, but for raising smaller supplies the possibility of using the wind as the motive power is always worthy of serious consideration.

Water Power.—Running water, when available in sufficient quantity, is one of the cheapest and most manageable sources of power for pumping purposes. It may be utilised by means of water-wheels, turbines, or rams, the choice often depending on the fall which can be utilised, the amount of water to be supplied, and the height to which it has to be raised; but in some cases, where any form is applicable, the selection will be influenced by minor considerations. Whilst water-wheels and turbines are occasionally used for pumping large quantities of water,

rams are rarely used when more than 10,000 gallons a day have to be raised. As the hydraulic ram, where it can be utilised, is probably the simplest and cheapest, it may be considered first.

Its construction will be rendered intelligible by the following section and description (Fig. 22):—

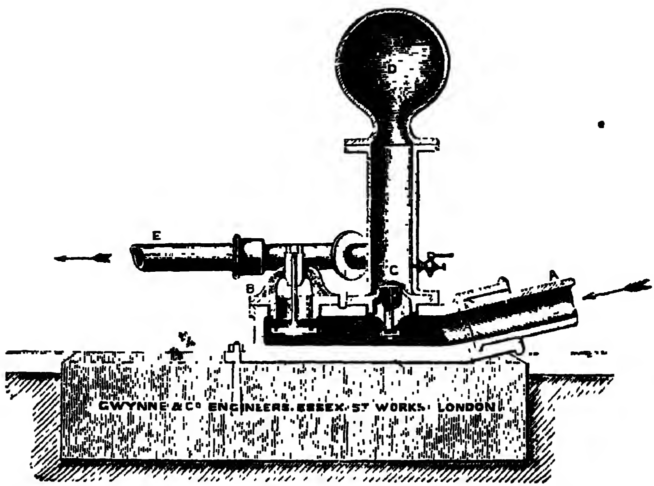

FIG. 22.—A is the feed pipe communicating with the reservoir supplying the water, B the escape valve, C the valve leading to the air-vessel, D, E is the rising main. When water is admitted to A, it at first escapes through the valve B, which opens downwards, but as the maximum velocity is reached the force is sufficient to close the valve. The flow being suddenly stopped, the pressure rises, and lifts the valve C, which opens upwards, a certain amount of water entering the air-vessel D. The pressure being relieved by the recoil, both valves fall. The water again escapes at B, and the action described is repeated. The intermittent flow into C is converted by the compressed air into a constant flow through the rising main E.

In this ram it is obvious that the water working the ram is the same as that which enters the rising main, and as the proportion of water raised to that wasted is invariably small, its utility is somewhat limited. Recently, however, a double-acting ram has been devised, whereby an impure

water by its fall is caused to pump water from a purer source. As yet these are not in general use.

These self-acting pumps work day and night, and if by a good maker, and properly adapted for the work they have to perform, the amount of attention and repair required during the year is remarkably little, as there are no parts requiring packing or lubricating. With a reservoir holding sufficient to meet one or two days' demand, repairs, when necessary, can be effected without interfering with the supply. Where large quantities of water are being pumped, a duplicate ram is desirable.

The smallest fall which can be utilised is about 18 inches; the greater the fall the larger the proportion of water, and the greater the height to which it can be raised. Although falls of 40 feet are sometimes used, the wear and tear, consequent upon the friction and shock necessitates the use of specially-constructed rams. Special rams are also made which will lift water a height of 800 feet, and the water so raised may be caused to act upon a second ram and raise a portion of the water to a height of 1,500 feet. Rams, however, are rarely used to lift water to more than 150 to 200 feet, as the amount of water wasted compared to that supplied increases with the elevation, but more rapidly than the elevation on account of the increased friction. A ram of best construction will raise water 30 times the height of the fall, but it is not safe to depend upon delivering it at more than 25 times the height. Where the water supply is not sufficient to work a ram continuously, it may often be dammed up and discharged at intervals by a syphon arrangement, the ram then working intermittently.

Theoretically, disregarding friction, the product of the amount of water falling in a given time into the fall should be equal to the product of the amount raised into the height. Thus 100 gallons falling 10 feet would raise 10 gallons 100 feet, 20 gallons 50 feet, or 100 gallons 10 feet, etc. Friction and imperfections in construction, however,

render such a degree of efficiency unattainable; but some of the best of most modern rams have reached over 80 per cent. of efficiency, even with a rising main of considerable length and when the water was being lifted over 100 feet. The smaller the fraction expressed by the ratio of the fall to the height raised, the less the efficiency. Tables giving the efficiency for different ratios have been published, but they are quite useless. Thus in a table recently issued the efficiency of a ram with a ratio of fall to height of $\frac{1}{12}$ is given as 37 per cent., whilst more than one English maker will guarantee at least 50 per cent., and 69 per cent. has been attained. Allowing for the friction in a moderate length of rising main, a good ram properly fixed should supply not less than the following percentages of the theoretical amount:—

$\frac{\text{Fall}}{\text{Height raised.}}$	Degree of Efficiency.	Efficiency attained by Blake's Rams.
$\frac{1}{2}$	86 per cent.	...
$\frac{1}{3}$	76 ,,	78 per cent.
$\frac{1}{4}$	70 ,,	83 ,,
$\frac{1}{5}$	66 ,,	72 ,,
$\frac{1}{6}$	63 ,,	...
$\frac{1}{7}$	60 ,,	75 ,,
$\frac{1}{8}$	58 ,,	...
$\frac{1}{9}$	56 ,,	...
$\frac{1}{10}$	54 ,,	...
$\frac{1}{12}$	52 ,,	69 ,,

Example.—It is required to know what amount of water can be raised to a height of 100 feet, by a ram working with a fall of 10 feet, the amount of water available being 20,000 gallons per day.

Here the ratio $\frac{10}{100}$ should give an efficiency of at least 54 per cent. With perfect efficiency the amount raised would be 2,000, since

$$2{,}000 \times 100 = 20{,}000 \times 10$$

and $2,000 \times \frac{54}{100} = 1,080$, which is the number of gallons per day the ram should be guaranteed to raise to the required height.

The efficiency decreases very rapidly when the ratio of the fall to the height raised exceeds $\frac{1}{12}$, so that when $\frac{1}{25}$ is reached the proportion of water pumped to that wasted becomes a very small fraction indeed. In such cases other forms of water motors are preferable; moreover, with a fall of over 10 feet the wear and tear becomes so very considerable that it is not desirable to attempt to utilise much greater falls with a ram. These conditions, therefore, limit the general usefulness of the ram to situations where the fall of water available is from $1\frac{1}{2}$ to 10 feet, and where the supply has not to be raised more than 250 feet.

A turbine can often be used where a ram is inadmissible. In the ram the pump is a part of the machine, whereas a turbine is merely a machine for utilising a fall of water to supply the power to work a pump or set of pumps. It follows, therefore, that a turbine worked by a falling stream may be used for pumping water from any source, as from a deep well, and the pumps may be placed at any convenient distance from the source of power, the connection being made by suitable gearing. Any fall from 1 to 1,000 feet can be taken advantage of, and there is practically no limit to the depth from which the supply can be raised, or to the height to which it can be propelled. Moreover, they can be so constructed as to work with fluctuating falls and a constant efficiency of 75 per cent. attained. In experimental trials the best turbines have yielded 87 per cent. of the actual power of the water, but even with the best makers it is not safe to rely upon more than 75 per cent.

The numerous varieties of turbines may be divided into two classes. In the first or "pressure" turbine the falling water is conducted through one or more pipes and allowed to impinge upon the vanes of a wheel, which revolves upon

a pivot and is included in a metal case. The impact of the water causes the wheel to revolve with a velocity depending chiefly upon the fall. After expending its energy, the water escapes around the centre of the case. The turbine may be fixed horizontally or vertically, and the vanes may be fixed or movable, the latter only being necessary where the power required or the water available is variable. In the second class of turbines or "impulse" turbines, the falling water (conducted by suitable guides) impinges against a series of "buckets," arranged around the periphery of the wheel. This turbine, therefore, need not be acted upon by the water all round, neither need the wheel be submerged. It must always be fixed at the bottom of the fall, whereas the "pressure" turbine may be placed as much as 20 feet above, the water escaping from the centre passing down a suction pipe and so contributing to the available power. The first form is most generally applicable for low and medium falls, and the latter for high falls. When the supply of water is abundant and a high degree of efficiency is not necessary, cheap forms of the turbine may be employed; but where it is required to fully utilise the power a machine should be obtained, the high efficiency of which is guaranteed. As large turbines are more efficient than small ones, it is often advisable to store the water during the night and give the whole out during the day to a large turbine, rather than work a smaller machine with the constant flow.

On the Continent turbines are much more used than in this country, the largest installation probably being at St. Maur, where four sets of turbines, each with a diameter of forty feet, raise over 8,000,000 gallons of water per day to an elevation of 250 feet for the supply of the city of Paris. The fall of water utilised is only 3 feet. The turbines are fixed with the axes horizontal, and are of the "impulse" class. The turbines pumping water for the city of Geneva

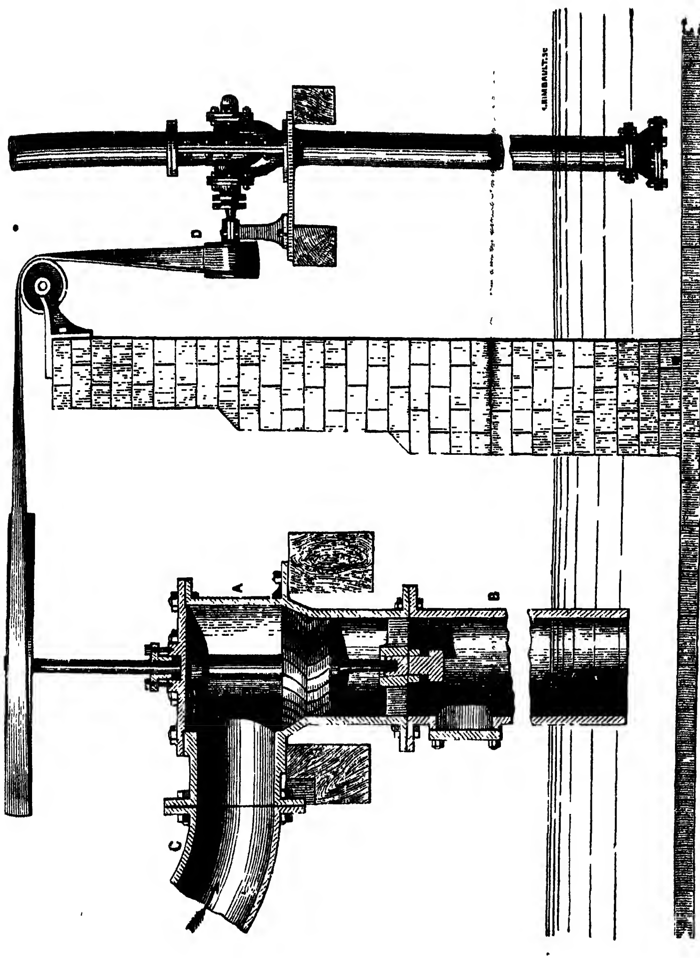

FIG. 23.—Section of Turbine. (Jonval's Principle.)
The pipe C is fed from the head of water, and the water in falling to the outlet B causes the revolution of the Turbine. The motion is conveyed by pulleys and belting to work the centrifugal pump D.

are of the same description, but work with a fall of 165 feet.

Probably the greatest height to which water is raised by any machine is by the turbines pumping water to supply the town of La Chaux de Fonds (population 30,000). These turbines, made by Mons. Escher of Zurich, work with a fall of about 100 feet of water, derived from the Gorges de l'Areuse, and throw that supplying the town to a height of over 1,600 feet.

As an example of a village supply the works recently executed at West Lulworth (Dorset) may be cited. The water from a spring on the hillside is piped to a tank placed on a tower immediately over the turbine. The vortex (pressure) horizontal turbine is fixed in a pit 20 feet below the level of the water in the tank. The water falls to the turbine by means of a vertical pipe, the waste water being conveyed away from the bottom by a 12-inch drain and discharged into the sea. From the turbine, which runs about 600 revolutions a minute, the power is communicated by a 10-inch pulley to a larger pulley on the overhead shafting, and thence the power is transferred to a set of three-throw plunger pumps. The machine is estimated to be of 5 h.p., and will lift continuously 1,200 gallons per hour into the service reservoir, which is on the hillside, 300 feet above the source of the water. The reservoir has a capacity of 60,000 gallons, and as the population to be supplied is only about 400, it is obvious that the reserve is ample to admit of the pumping being intermittent, and to give time for repairs, etc., to the turbine when such are needed.

The efficiency of turbines decreases with the size; hence for small supplies (of from 1,000 to 4,000 gallons per 24 hours) a small water-wheel, which can be used without gearing, is often more economical, both in first cost and in amount of water used. Water-wheels are too well known to need any description. Recently, however, the substitution of light iron wheels for the cumbersome wooden ones

previously used has greatly increased the utility of this machine. An "overshot" water-wheel receives the water near the top and has a higher degree of efficiency than either the "high breast," which receives the water above the centre, or the undershot wheel, which receives the water below the centre. Where sufficient fall is available, therefore, the overshot wheel should always be selected. A fall of 1 foot may be utilised for driving an undershot wheel, but not less than 3 feet is required for the overshot. They are quite as reliable as rams, and as the wheels revolve at a slow speed the shaft can be directly connected with the piston rods of the pumps. Where the water available for working the wheel is variable, an adjustable disc crank can and should be provided, so as to enable the stroke of the pump to be correspondingly varied. The following table gives approximately the amount of water which can be raised per day to a height of 100 feet, with wheels of different diameter and with different supplies of water:—

Diameter of Wheel.	Water Supply per Minute.	Quantity raised 100 Feet in 24 Hours.
4 feet	60 galls.	1,000 galls.
4 ,,	100 ,,	1,850 ,,
4 ,,	500 ,,	9,250 ,,
5 ,,	50 ,,	1,000 ,,
5 ,,	100 ,,	2,000 ,,
5 ,,	250 ,,	5,000 ,,
6 ,,	100 ,,	2,750 ,,
6 ,,	500 ,,	13,750 ,,

These figures refer to an "overshot" wheel. A "high-breast" wheel would raise about 5 per cent. less, and an "undershot" about 15 per cent. less, assuming the fall utilised to be the same. As these wheels run night and day, rarely require any attention, are very inexpensive both to purchase and fix, and can be worked by impure

water, whilst raising a pure water from a well, spring, or other source, it is obvious that under many circumstances they are preferable to a ram, whilst under others they can be used when the ordinary ram is inadmissible.

Fuel Engines.—Where neither wind nor water are available an engine, deriving its energy from the combustion of fuel (coal, wood, charcoal, petroleum, or gas), must be employed. Such engines differ from those previously described in being a constant expense for fuel and attention; but the great improvements which have been effected in recent years, especially in the construction of small motors, has probably reduced this expenditure to a minimum. The simplest machines are those which dispense with the use of steam. These are the hot-air, gas, and oil engines. The competition between the makers of these various types of motors, not only amongst themselves, but with the makers of steam engines, has resulted in all being brought to such perfection that it is often a difficult matter to decide which form is the most desirable. The hot-air engine is very compact and economical, requiring but little fuel and skilled attention, but it is only adapted for small works, where the h.p. required is from ¼ to 1. Its only competitor under such conditions is the gas engine, and as this is quite as economical in cost of fuel where gas is reasonably cheap, and requires even less attention, it would probably be selected where gas is available. The gas engine is rapidly supplanting the steam engine in all but the largest pumping stations, since they are not only more compact than steam engines, but, with gas at a reasonable price, more economical, when the great saving in repairs and in attendance is taken into consideration. When once started they will run for hours without any attention, and there is no risk of explosion from neglect. "Oil" engines are of more recent introduction and, owing to the cheapness of petroleum, are claimed to be more economical than gas engines should the cost of gas be over 2s. 6d. per 1,000 feet.

It is also asserted that the cost of the oil used does not exceed that of the corresponding amount of coal required in driving a steam engine, when such coal can be obtained at 10s. a ton. Where coal is more expensive there is a saving in the cost of fuel, but in all cases there is saved the wages of stoker and driver and the cost of water. As the oil used has a high flashing point there is no risk of explosion, and the danger from fire is reduced to a minimum. In the best machines the vapouriser is heated by a small lamp, taking about 5 to 15 minutes. As soon as the temperature is sufficiently high the engine will start when the fly-wheel is turned. The vapouriser is afterwards maintained at a sufficiently high temperature by the continuous explosions. When once started the only attention required is periodical lubrication and the occasional replenishing of the oil reservoir. In fact, after being set in motion it requires no more attention than the gas engine.

These engines are now made to work up to 40 h.p., and where gas is not obtainable there is no doubt that they will be extensively employed.

In order to enable gas engines to compete with oil engines where there is no public gas supply, plants are now made for converting petroleum oils, fat and grease of all kinds, into gas, and it is claimed that the gas so produced is cheaper than coal-gas. Water-gas may also be manufactured and used for this purpose. As the "oil" engines convert the petroleum into gas in the vapouriser drop by drop as it is required, there does not seem to be any advantage in or any necessity for constructing a gasworks, unless gas is required for other purposes besides that of supplying the motive power to the engine.

Steam engines, except for large waterworks, are not likely to be seriously considered as a source of power on account of the comparatively large expense entailed in labour. For large works, however, they continue to be the only practical and efficient motors. In such cases, also, the

compound condensing engine will be used. For engines under 10 h.p. the saving effected by the use of a condensing arrangement will not compensate for the additional cost of the engine. The pumps may be driven by a steam engine either directly or through the intervention of a crankshaft and fly-wheel. In the former case the pistons of the cylinder and of the pump are continuous, in the latter the piston of the cylinder acts upon the fly-wheel and the pump piston is attached to a crank. The crankshaft engine requires more space and stronger foundations than the "direct" form, and as the latter are now being made "compounding" and with high duty gear, and are more compact, they will be generally preferred.

In calculating the horse power required for pumping a supply of water, the chief factors are: (*a*) the quantity of water to be raised, and (*b*) the height to which it has to be lifted or forced. Besides this, an approximate estimate must be made of the power which will be required to overcome the friction due to gearing, and the passage of the water through the pipes. The loss from friction in the pipes will depend upon the nature of the surface of the pipe, degree of smoothness or roughness, but more upon the diameter and velocity with which the water is traversing it. It is of the highest importance to have all the mains of sufficient diameter, since the friction increases with the square of the velocity. Thus the friction in a pipe discharging a certain number of gallons per minute will be increased fourfold if the discharge be only doubled. The friction also increases directly as the length of the main. The main should always be of such diameter that the velocity shall not exceed 2 feet per second (Rawlinson). With this velocity the discharge from pipes of different diameters is given in the following table. It will be observed that the volume for any pipe can be calculated by multiplying the square of the diameter in inches by the volume discharged from a 1-inch pipe:—

Diameter of Pipe.	Volume of Water discharged per Minute with a Velocity of 2 Feet per Second.
1 inch	4·1 gallons
$1\frac{1}{2}$ inches	9·2 ,,
2 ,,	16·4 ,,
3 ,,	37·0 ,,
4 ,,	65·0 ,,
6 ,,	148·0 ,,
8 ,,	260·0 ,,
10 ,,	410·0 ,,
12 ,,	590·0 ,,

With pipes of such ample diameter the loss from friction is very small and practically negligible.

An engine of one * actual horse power will raise 3,300 gallons 1 foot high per minute, and any smaller quantity to a proportionately greater height. From the following simple formula the h.p. required to pump any given quantity of water can easily be calculated:—

$$\frac{G \times H}{3{,}300} = \text{H.P.},$$

where G = the number of gallons to be pumped per minute and H = the height to which it has to be raised.

The allowance for overcoming the friction of the bucket or plunger in the pumps, and of the movement of the water in the pipes, and for raising the piston rods (when pumping from a deep well), cannot be exactly calculated. It is better to err on the safe side and allow 80 per cent. for small engines and 40 per cent. for larger powers.

In all waterworks it is necessary to provide more pumping engines than are actually at any one time required, in

* By actual horse power is meant the actual power of an engine given from the shaft or fly-wheel. The term "indicated" horse power, which is frequently used, is the power given off in the cylinder, and is, of course, higher than the actual or available power. Another term often employed by makers of engines is "nominal" horse power. It is a variable quantity, and so misleading that it should be abandoned.

order to provide for such contingencies as a break-down or laying-off for repairs. "In the case of small waterworks it is common to have double the quantity of power needed, in the form of two pumping engines, either of which is capable of doing all the work. The reason for this is that the first cost would probably be rather increased than otherwise, by subdividing the work more when the engines are very small, even although the total horse power might be less. Thus suppose the total horse power needed were six i.h.p.* Two engines of six i.h.p. each would probably not cost more than three of three i.h.p. each; moreover, in work, the efficiency of the one pumping engine of six i.h.p. would be greater than that of the two of three i.h.p. each. Of course there is no hard-and-fast line between small and large works, but it may be very roughly said that it is not advisable to subdivide the pumping power into more than two engines if, by so doing, separate engines of less than ten i.h.p. each have to be provided. In the case of large water-works the stand-by power need only equal one-third, one-fourth, or, in the case of very large works, perhaps one-fifth of the whole, there being, in such cases, three, four, or five pumping engines" (Burton, *The Water Supply of Towns*). Where engines are employed requiring the use of fuel and attendance, it is desirable to have the machinery of such power that the whole of the water required during twenty-four hours can be pumped in a much shorter time. For mansions, farms, etc., the engines may be sufficiently powerful to raise in eight or twelve hours as much water as will serve for three or four days, thus necessitating pumping only twice a week. For village water supplies pumping for from four to six hours daily should suffice. For towns up to 20,000 inhabitants the pumps should raise in ten hours the whole day's supply. For larger towns the pumping would probably be continuous. Naturally the h.p. required will have to be regulated by the quantity of water which has to be raised in the given time.

* Indicated horse power.

CHAPTER XXII.

THE STORAGE OF WATER.

WHERE a water supply is derived from the rainfall upon any catchment area, it is obvious that, whether it is to meet the demand of a single house, or of a whole town, sufficient storage must be provided to tide over the longest periods of drought ever likely to occur, and to equalise the supply during a succession of dry seasons. The various ways in which the amount of storage necessary is calculated, and the opinions of various engineers and hydrologists thereon, have already been recorded in Chapter XVII., where the amount of water available from different sources has been considered. The reservoirs used for the above purposes are called "impounding" reservoirs, and when of large size they are usually situated in a valley, or at the junction of two valleys, where, by excavation and the construction of a dam, a sufficient quantity of water can be collected.

The ground must be first surveyed to ascertain the character of the impervious stratum and its distance from the ground surface. If of rock, its freedom from fissures (common in certain formations), through which the water could escape, must, if possible, be determined. The presence of an undiscovered fissure may result in the reservoir, after construction, having to be abandoned, or in the expenditure of large sums of money in detecting and attempting to remedy the defect. The dam may be of masonry or of earthwork, but the former is only applicable where there is a rocky foundation. The latter can be

constructed on rock, clay, or other impervious strata, and is less costly than masonry. If, however, the water is once able to penetrate it, the channel will continuously increase in size and the dam will be destroyed, whereas defects in masonry dams have not this tendency to continuous increase and admit of being more easily discovered and remedied. All vegetable matter should be removed from the sides and bottom of new reservoirs, otherwise these, by their decomposition, will give up organic matter to the water, favourable to the growth of low forms of life. To draw off the water a valve tower is provided, which admits of valves being opened at various depths, so as to avoid drawing either from too near the surface or too near the bottom. A meter house may be required, in which to fix the apparatus for recording the amount of water which is passing into the mains, or the amount of compensation water being supplied, or both, and a by-pass to allow of flood water being diverted from the reservoir, and to prevent the water rising above a certain level.

According to Rawlinson, the outer portion of the embankment must be effectively drained, and if there are springs of water in the puddle trench (as there usually are), these must be collected and brought away. No form of culvert or other works for drawing off water should be constructed within or beneath or through the deepest made portion of the bank, but the outlet tunnel, valve chamber, and works connected with the drawing off of the water must be in the solid ground, on the side of the valley. At the centre of the bank the valve chamber should be formed. All pipes and valves should be so placed as to be easily reached for repairs or renewals, and it should be so arranged that no valve in the tier of valves in the valve well need be worked under a greater head than 10 or 15 feet.

Referring to storage reservoirs, Whitaker, in his anniversary address to the Geological Society,* says:—

* *Quart. Journal Geol. Soc.*, 1899.

"In the selection of sites for reservoirs more particular points have to be considered, especially where high dams are to be constructed. In such work it is well, as far as possible, to avoid places where there is any great disturbance, whether by faulting or otherwise.

"Masses of Drift, too, are sometimes troublesome, and it may be needful to study the composition of these and their relation to the rocks beneath; irregular mixtures of permeable and impermeable yielding material are likely to cause trouble, and the uneven way in which Drift so often occurs leads to uncertainty as to its thickness. On the whole, therefore, those parts of a valley with much Drift are to be avoided, although sometimes a bank or sheet of solid Boulder Clay may be useful. Professor Boyd Dawkins has lately drawn attention to this matter, in a lecture delivered to the Institution of Civil Engineers,* noticing a case, at the Ogden Reservoir (for Sheffield), where Boulder Clay made a more or less water-tight bottom, and another (Yarrow Reservoir, Rivington) where Drift (sand, gravel, Boulder Clay, and loam) filled up a deep pre-Glacial valley and caused much difficulty.

"Tracts in which there are large landslips are clearly dangerous; for, with rocks as with men, where a slip has occurred, there another is likely to happen some day, as witness the Sandgate landslip of 1893, which was within the area of an older slip. Moreover, the process of cutting into a slipped mass of rock and earth is likely to start fresh slips, and to endanger the stability of the work. An instance of this may be given from the Manchester Waterworks in the Valley of the Etherow, several miles east of the city, made many years ago, when the characteristics of old landslipped tracts were not so well recognised as now. The lower part of the deep valley along which the set of reservoirs has been made is in Millstone Grit; but, above

* Proc. Inst. Civ. Eng., vol. cxxxiv. (1898), p. 270.

this, the part in which most of them are placed has been cut through the Millstone Grit to the Yoredale Beds, especially on the southern side. The Yoredale Beds being largely composed of shale, the conditions are favourable to springs and slips, and, as noted on the Geological Survey map (Sheet 88, S.E.), the greater part of the southern side of the valley is a landslip-area. The features of this are very clear, especially in the neighbourhood of the Woodhead Reservoir, the highest of the series, the dam of which impinges on the landslip, by Crowden Station. Under these circumstances, one is not surprised to hear that this reservoir was, for some years, never filled to within 15 or 20 feet of its height, because it was thought unsafe to fill it, owing to a landslip and to the unsoundness of the embankment, until a new embankment had been made. I understand, indeed, that the dam is now practically double.

"In the above remarks I am not finding fault with this fine set of works, but only showing how difficulties, of a nature that a geologist would expect, interfered with the plans of so good an engineer as the late Mr. Bateman. I am inclined to think, indeed, that old landslips are more common than most geologists suppose. In my Geological Survey work in Hampshire I found that the right, or western, bank of the Test, near Romsey, was for a long distance a great slip, with the usual irregular features; and later on the same was found to be the case with the left, or eastern, bank of the Itchen opposite Southampton. In both cases no beds in place could be seen, except the gravel at the top. So far as I know, these two occurrences had never been noticed; but many others have been observed, especially in the later work of the Geological Survey.

"Another matter that may give trouble in a reservoir, and has to be guarded against, is the occurrence of permeable beds through which the water may find a way to lower ground, under favourable circumstances. An example of this may be given from another set of reservoirs

of a like kind to that already noticed, along the valley of the Loxley for the supply of Sheffield. That portion of the valley in which the reservoirs are placed is cut out of the upper part of the Millstone Grit Series, which consists of alternations of grits and shales. From the slight easterly dip of the beds, down the valley and at a higher angle than the bottom-slope, the Middle Coal Measures are carried down to the bottom by the eastern end of the Damflask Reservoir, and in part the sides and bottom of this reservoir consist of a porous grit, down which water passed to below the dam. To get over this difficulty a long trench had to be made along the southern side and filled with water-tight materials."

In cases also where the water is derived from springs and streams of variable flow, the supply sometimes falling below that of the average demand, impounding reservoirs are necessary to equalise the supply. The size will depend upon many circumstances, but will be chiefly influenced by the length of time during which the yield is below the average, and by the extent of the fluctuations. Where river water is impounded it must also be remembered that at certain periods, following heavy rains, the water will be more or less turbid or impure, and may have to be allowed to run to waste. Where the average supply of a stream is more than sufficient to meet all requirements, more or less storage is still required to enable pure water to be supplied whilst the river is in flood and its waters turbid and possibly polluted. Wherever the water collected requires to be filtered before being delivered to the consumer, reservoirs for "settling" are an almost indispensable adjunct to the filter beds.

Such "settling" reservoirs retard the clogging of the pores of the sand in the filter beds, and therefore enable the filters to work for longer periods without cleansing. They should be so constructed as to allow of emptying and cleansing, but should not be too shallow, otherwise the

water may become unpleasantly warm in summer. A water depth of 12 to 16 feet is usually recommended. As generally constructed, with sloping sides, the growth of algæ is favoured. Vertical sides are preferable.

Smaller or "service" reservoirs are often also constructed in or near the place to be supplied with water, in order to enable a constant average flow to be maintained to meet the very varying demand during the 24 hours. These are especially necessary where the water has to undergo a process of filtration, in order that the process may be uniformly continuous. Without such a service reservoir, during the period of greatest demand imperfectly-filtered water would pass into the mains, unless filter beds of an otherwise unnecessarily large area had been provided. These reservoirs are also commonly used when water is raised by pumping. Without such storage it is evident that pumping would have to be continuous, and that the rate would have to vary with the demand, whereas with a service reservoir the pumping engines may work at a uniform speed, and for only a portion of the 24 hours.

When the source from which water is derived is at a considerable elevation, and long lengths of main convey the water in different directions, as to villages and towns *en route* to its ultimate destination, service reservoirs are often constructed at elevated points, not only to break the pressure, but to enable smaller mains to be used. Without these reservoirs the mains would have to be capable of supplying the maximum consumption, whereas with storage, the mains, as far as the reservoirs, need only be capable of delivering the average demand. As the maximum hourly consumption may be twice the mean consumption, the difference in first cost, where the mains are of any length, is very considerable.

Another very important advantage of such reservoirs is that in case of fire there is a reserve of water instantly available. This is especially valuable in connection with

the supply of small towns, villages, mansions, and farms, since the amount of water likely to be used in case of an outbreak of fire would be a large fraction of, or might even exceed that of the whole capacity of the mains, whereas in large towns the increased demand would only be a small fraction of the average supply.

The amount of storage necessary and its character depends upon the mode of supply, and whether by gravitation or by pumping. Writing of these two classes of waterworks, Burton, in his work on *The Water Supply of Towns*, says:—

Gravitation works to be complete must consist of—

1. Either a high-level impounding reservoir, or a high-level intake with a settling reservoir.
2. Filter beds.
3. A service reservoir near the impounding or settling reservoir, or, if there is high land conveniently situated, a reservoir as near as possible to the town or within it, or one or more high-level tanks within the town.
4. A distributing system.

A pumping system may consist of—

A.—1. A comparatively low-level intake.
2. One or more settling reservoirs.
3. A set of filter beds.
4. A pumping station, with
5. A high-level reservoir or tank near or within the town, holding enough to compensate for the inequality of the consumption during 24 hours.
6. A distributing system.

B.—Where there is no land for a high-level reservoir, and a high-level tank on an artificial support to hold enough water to compensate for the variation in consumption during 24 hours is considered impracticable.

1. A comparatively low-level intake.

2. One or more settling reservoirs.
3. A set of filter beds.
4. A low-level service reservoir.
5. A pumping station with engines pumping directly into
6. A distributing system.

C.—When the intake is so low that the water will not gravitate to any convenient place for settling reservoirs and filtering beds, and there is room for these only on low ground.

1. A low-level intake.
2. An intake pumping station with engines pumping into
3. One or more settling reservoirs.
4. A set of filter beds.
5. Main pumping station with engines pumping into
6. A high-level reservoir on a high artificial support, and
7. A distributing system.

D.—The same as before, C, up to 5, but

5. A low-level service reservoir.
6. Pumping station, with engines pumping into
7. A distributing system.

The last case, as that of B, occurs where there is no natural site for a high-level reservoir, and where a high-level tank of sufficient size on an artificial support would be too expensive, or is, for any other reason, impracticable.

Under peculiar circumstances modifications of these systems may be and are adopted, and, of course, when the low-level intake is a well or spring yielding water invariably pellucid, the settling reservoirs and filter beds are dispensed with, and the system is much simplified, the water being forced directly into a high-service reservoir or even into the distributing mains.

Impounding reservoirs must be of ample size, not only to meet present demands, but also such increased demand as

may arise in the more immediate future. Where large works are being constructed 50 years is not an unreasonable length of time to look forward to, and as a minimum the probable increase in 30 years should be provided for. Many towns have been recently subjected to immense inconvenience and anxiety on account of this neglect, or from under-estimating the growth of the population and the consequent increased demand for water.

The conditions which affect the decision as to the size of settling and service reservoirs are of a different character, but probably the most important is the effect of storage. This varies somewhat with the character of the water; speaking generally, the purer the water the less the liability to change. In natural reservoirs, or lakes, water is less prone to be infested by organisms, which affect the odour and taste, than in artificially-constructed reservoirs. Pure surface water contains too little organic matter to favour the growth of these algæ and fungi, and the effect of storage is beneficial rather than otherwise; yet cases are recorded where very pure waters have developed an objectionable odour and taste. These growths are usually found to occur in reservoirs storing water collected from gathering grounds which are in part cultivated. The small amount of manurial matter, or the products of its oxidation taken up by the water, supplies constituents necessary to the growth and multiplication of these low forms of life. Peaty water tends to lose its colour if long stored, probably from the action of light, but the observers for the Massachusetts Board of Health, who have very fully studied the effect of storage, found that 12 months' exposure was necessary to completely bleach such water. They found that surface waters, by storing, suffered no change in the amount of ammonia and nitrates present, but in other waters the nitrates were slightly reduced. Investigating waters taken from various depths from a deep but small lake, they concluded that vertical circulation took place during the

winter months, but that during the summer this was in abeyance, and that the water at the bottom of the lake remained stagnant. When the air is colder than the water, the surface of the latter will cool, becoming at the same time denser and tending to sink; when the air is warmer than the water, or the latter is exposed to the direct action of the sun's rays, the surface will become heated, and, decreasing in density, will retain its position. This, of course, applies to water stored in large or small reservoirs, provided the water is exposed to the air. The result of the stagnation is probably very slight in waters of great hygienic purity, but in waters containing organic matter the free oxygen disappears, the water deteriorates, free ammonia increasing in amount, especially at depths below 20 feet, and at such times samples of water from near the top and near the bottom may yield very different results upon analysis.

Ground water when stored in open reservoirs is said to "deteriorate at all seasons of the year." The albumenoid ammonia, or rather the organic matter yielding ammonia upon distillation with alkaline permanganate, increases, and in spring and summer the free ammonia becomes excessive, and at the same time nitrates are reduced. The micro-organisms, which in the water at its source are few in number, increase rapidly, so that they may even be in excess of those found in much more impure waters. The same water when kept in covered tanks is said to suffer but an inappreciable change; this is attributed to the absence of light and the difficulty of access of air-conveyed microbes. I have frequently observed, however, that the waters taken from a whole series of wells over a definite area yielded much better results both chemically and bacteriologically when examined in winter than when collected in summer. In small open tanks through which water is constantly passing, the water undergoes, as a rule, but little change, but numerous instances are recorded of the rapid and

persistent growth of organisms even in service tanks. This is almost certainly prevented by thoroughly cleansing and covering the tanks. One organism, however, grows better in the dark than in the light, the "Crenothrix," and occasionally gives rise to trouble by imparting a nauseous odour and taste to the water. As this fungus requires for its growth both protoxide of iron and organic matter, a water in which it can flourish is not desirable for a domestic supply.

The results of all the observations which have been made on storage as affecting the size of service reservoirs lead to the conclusion that it is desirable to reduce this storage to the minimum compatible with safety. It is only necessary, therefore, to consider what capacity is required for compensating for the inequality of the hourly consumption, and for a reserve in case of fire.

Inequality of Hourly Consumption.—Whilst the maximum consumption for a whole month rarely exceeds by 30 per cent. the mean for the year, the maximum hourly consumption may exceed this by 100 per cent. Mr. J. Parry, M.Inst.C.E., found in Liverpool during 1893 that the maximum weekly consumption took place in July, when it was 15 per cent. above the mean, and that the minimum occurred in November and December, and was 9 per cent. below the mean. The highest hourly rate at which water was delivered was between 10 and 11 A.M. on 6th July, when the delivery was at the rate of 50 gallons per head, or 85 per cent. above the average for the year. Mr. Parry says, "The weather at the time was exceptionally warm, and it is not probable that the difference between the mean and maximum rate of discharge could ever exceed this amount." Experiments which have been conducted in Germany, however, have shown a greater variation than this. Taking the mean of a number of records from various waterworks, and taking the mean annual consumption as 1.0, the maximum daily discharge was 1.4, and the maximum

hourly 2.1. The minimum flow is of trifling importance; in nearly all cases where waste is prevented as much as possible, the flow during some portion of the night approaches zero.

It is easily demonstrated that a service reservoir capable of holding 7 hours' mean supply would be amply large to compensate for all inequalities in the demand for ordinary purposes, but in small towns there would be but a small reserve in case of fire.

Reserve for Fire Extinction.—In many cases little reserve for this purpose is required, since by means of a by-pass or by increased pumping all the necessary water may be rendered available. Where such is not the case Burton gives a formula for estimating roughly the amount of water which should be stored for the special purpose of fire extinction:—

$$Q = 200\sqrt{P},$$

where Q = the quantity to be stored in cubic feet and P the population of the town. This formula gives 125,000 gallons as the storage for this purpose in a town of 10,000 population, and 1,250,000 for a city of 1,000,000 inhabitants, or 10 hours' mean supply for the former and 1 hour for the latter.

To compensate for the inequalities in the demand for domestic purposes and for use in case of fire, 17 hours' storage in the smaller town and 8 hours' in the larger would suffice. In any case 1 day's supply should be ample. This is a reasonable mean between the estimates of those who recommend 6 or 7 hours' storage and those who would provide two or three days' storage. Where such an amount cannot be kept in reserve the pumping machinery must be sufficiently powerful to supply the additional quantity, or if the water flows by gravitation from impounding reservoirs the service mains must be large enough to carry it.

In moderate-sized towns the service reservoir may be placed upon an elevated tower of brick, stone, or ironwork. The tank should be constructed of wrought or cast iron, covered to exclude light, heat, and dust, and it should be divided into two or more compartments for convenience in cleansing. Where placed upon a natural elevation it may be of brickwork rendered in cement. In larger towns, where there is no elevated ground sufficiently near, and the erection of tanks on towers would be too expensive, storage must be dispensed with, and the mains, if a gravitation system, must be sufficiently large to supply the maximum demand; or if a pumping system, the pumping engines must be so constructed that the pumping corresponds exactly with the consumption. A constant pressure may be obtained from a stand pipe or by means of an air chamber. A float within the stand pipe can be made to adjust the speed of the engine or the stroke of the pumps, decreasing when the water rises and increasing when the water falls, or the pressure in the air chamber may be caused to automatically check or accelerate the action of the pumps.

In Chapter II. reference was made to the storage of rain water for the supply of cottages, farms, and mansions. Denton recommends that the tanks used should be capable of holding 120 days' supply, but few mansions or farms have sufficient roof area to allow of anything like this quantity being collected even in the wettest seasons, whilst the average cottage could not collect more than half this amount. A tank capable of holding one-third of the rainfall is probably as large as ever could be filled, and it is useless constructing tanks to hold more water than can be collected, and absurd to think of compensating for a too limited collecting area by increasing the storage capacity. Only the excess of rainfall over and above that used during the rainy season can be stored, and the smaller the collecting

areas, the smaller will be the surplus and the smaller the tank which is necessary for storing it.

Rain-water tanks are usually placed underground, where it is almost impossible to ascertain if they are water-tight. They are difficult of access and more difficult to cleanse. Tanks fitted with rain-water separators and filters can be constructed above ground, and are in every respect preferable. Underground tanks, if cut out of solid chalk or sandstone, merely require lining with cement. Tanks constructed in pervious soil must be made of brickwork in cement and be rendered in cement, and arched over with the same materials.

Where water has to be pumped for single houses or small groups of houses, in calculating the amount of storage necessary it must be remembered that the inequalities in the demand will vary to a much greater extent than when a whole village or town is being supplied. For this reason the tank must be larger in proportion, and also because provision must be made for such contingencies as the breakdown of the pumping machinery and an outbreak of fire. A comparatively small quantity of water at the moment when a fire is discovered may suffice to prevent a conflagration; hence, if possible, some provision should be made to render a supply readily available. It has already been pointed out that water tends to deteriorate in quality when stored in tanks; therefore it is better, if possible, to have a separate reservoir for storing water for fire extinction. Where valuable property is concerned, as in mansions and large farms, the additional expense incurred may prove a valuable investment. The size of tank required if the water is to be utilised for all purposes will depend upon (1) the amount desired to be stored in case of fire; (2) whether the pumping is constant, as by a ram, turbine, or water-wheel, or (3) intermittent and at irregular intervals, as when the pumps are worked by a wind engine, or (4) intermittent but at regular intervals, as when manual

labour or some form of gas, oil, hot-air or steam engine is used. Leaving (1) out of consideration, with the second or fourth arrangement a tank holding 2 to 4 days' domestic supply would be ample. With the third system there should be storage provided for from 7 to 12 days' domestic If the same tank is required to store water for fire extinction, it must be larger, according to the quantity considered necessary for use in such an emergency. Where there is an ample amount of water at the intake and a steam or similar engine is used for pumping, the fire reserve needs not be large, since the engines can speedily be set to work and the reserve supplemented.

The possibility of water being injuriously affected by the materials of which small tanks are often made has been mentioned in Chapter IX., and the advantages and disadvantages of storing water in house cisterns, necessitated by an "intermittent" public supply, will be referred to in the next chapter on "The distribution of water."

Where the water supply is "constant," there should be no necessity for storage cisterns in private houses. But where the supply is only "constant" in theory, and not in actual practice, as in many parts of London during seasons of drought, these cisterns must be retained; but in such cases draw-off taps should be affixed to the rising main for the supply of water for dietetic purposes. Of course this cistern should not directly supply any water-closet or place of similar character. Where the water supply is "intermittent," a storage cistern capable of holding one day's supply is absolutely necessary.

CHAPTER XXIII.

THE DISTRIBUTION OF WATER.

It is now generally admitted that no public supply is entirely satisfactory unless the mains are constantly full and under pressure—that is, unless the supply be "constant." Under the mistaken impression that the amount of water supplied would be economised, most of the older waterworks only admitted water to the mains for one or more hours daily, during which time the house cisterns were filled, and the amount used in each house was limited by the capacity of its cistern. This "intermittent" system is now being gradually abandoned, since, as we have already seen, a constant supply when properly superintended is equally, if not actually more economical. The risk of the water becoming polluted in the mains (*vide* Chapter XI.) is also reduced to a minimum by keeping them constantly full and under pressure, and in case of fire a supply of water is more readily available. As the whole day's supply has not to be delivered in a very few hours, the mains need not be so capacious, and house cisterns are no longer necessary. The disadvantages of such cisterns are numerous. Usually placed in inaccessible situations, uncovered or imperfectly covered, and constructed of unsuitable material, they are a frequent cause of the water becoming fouled, or of its becoming unpalatable from the heat, and a severe frost is more likely to cut off the supply. For these reasons no engineer would now suggest the adoption of the "inter-

mittent" system, and it is to be hoped that where adopted it will soon be abandoned, and that every house over the areas supplied will have a constant service at high pressure.

Whilst open conduits may convey water from the intake to the filter beds, covered conduits or cast-iron pipes must be used for carrying water from the filter beds to the service reservoirs. Where the pressure is but slight earthenware pipes may be used, or masonry, or brickwork, but iron will probably be cheaper than the latter. For such aqueducts a fall of 5 feet per mile will suffice for pipes of 2 feet in diameter, and a fall of 17 feet should not be exceeded. Earthenware pipes are not desirable, but if used must be laid in a well-puddled or concrete-lined water-tight trench, and if valleys have to be crossed the syphon portion must be of cast-iron to withstand the pressure, and means should be provided to wash out the syphon at its lowest point. In pumping mains the velocity of the water should be about 2 feet per second, and in no case exceed $2\frac{1}{2}$ feet. To allow for growth of population, increased demand and corrosion of pipes, a velocity of $1\frac{1}{2}$ feet in the first instance will probably be as large as can be adopted with safety. (The power expended in pumping varies directly as the cube of the velocity; hence, what is saved by using smaller pipes is more than lost in the cost of power.) In gravitation mains a little higher velocity, 3 feet per second, is permissible.

For calculating the velocity with which water will pass through cast-iron mains when first laid, Eytelwein's formula is fairly reliable:—

$$V = n\sqrt{\frac{dh}{l + 50d}},$$

where V = the velocity in feet per second; d, the diameter of the pipe; h, the head of water; and l, the length of the pipe in feet. In new pipes $n = 50$, but its value decreases with the corrosion, and may sink as low as 32. The factor

50*d* may be disregarded in pipes more than a few hundred feet in length. Sharp bends should be avoided, since they increase the friction and retard the flow. Where the pipes follow the contour of the ground, air-valves should be attached to the highest points. All pipes used should have previously been tested and proved to be capable of withstanding twice the pressure to which it is calculated that they will be subjected.

A "trunk" main conveys the water from the service reservoir to the confines of the districts to be supplied. It then breaks up into "distributing" mains, one for each district. The "distributing" mains supply "service" mains, and from these latter are taken the "house service" mains or "communication pipes." No service main should be less than 3 inches in diameter, and in towns it is never desirable that they should be less than 4 inches. In many American cities the minimum is 6 inches.

For the sake of economy mains of too small diameter are frequently employed, and the mistake when discovered is a costly one to remedy. A common error is to suppose that the flow of water varies only with the sectional area of the main, but a glance at Eytelwein's formula is sufficient to disprove this. For example, with a head of 100 feet and a main 10,000 feet long, what will be the flow from a 3-inch and a 6-inch main respectively? In the first case—

$$V = 50 \sqrt{\frac{\cdot 25 \times 100}{10{,}000}} = 2 \cdot 5 \text{ feet per second,}$$

and the flow $= V \times d^2 \cdot 7854 = \cdot 1227$ cubic feet per second.

In the second case—

$$V = 50 \sqrt{\frac{\cdot 5 \times 100}{10{,}000}} = 3 \cdot 5 \text{ feet per second.}$$

and the flow will be ·687 cubic feet per second.

The loss of head on account of friction is a still more serious matter when it is intended that the water shall be

available for fire-extinguishing. Thus, to quote an example from Merryweather's *Water Supply to Mansions:* "The passage of 300 gallons of water per minute through 500 yards of 4-inch pipe will absorb in friction a head of 172 feet, whereas if 5-inch pipe be used, only 57 feet will be absorbed; that is, assuming the reservoir to be 200 feet above the house, if you lay the 4-inch pipe 500 yards long, when delivering 300 gallons per minute the head or pressure on the jets will only be 28 feet, and the height of the jets about 20 feet, but with the 5-inch pipe the head will be 143 feet, and the height of the jet will be 100 feet; in each case the balance of the 200 feet is absorbed by the friction of the water against the sides of the pipe."

In certain towns—Liverpool, for instance—special mains are laid through the business parts for supplying water for extinguishing fires. In the residential parts the same mains act as fire mains as well as service mains.

Cast-iron pipes are practically universally used for distributing and service mains, and these should be properly varnished within and without. This varnish generally imparts to the water, for a time, a tarry flavour, which, although objectionable, is not injurious. After long keeping the varnish imparts less flavour to the water, but pipes so kept are not so durable as those laid down soon after being coated. Turned and bored joints are cheapest, but engineers are divided in opinion as to whether these or joints made with lead are the best. The latter are more flexible, and should alone be used where the ground is not firm or where there is danger of subsidence. Where turned and bored joints are used, an occasional lead joint should be introduced to allow for the elongation and contraction caused by changes of temperature.

To prevent the undue influence of the variations of the earth's temperature, Rawlinson says that the mains should be laid at a minimum depth of not less than 3 feet. Other

engineers give 2 feet 6 inches as the minimum, but in England the water in mains at the latter depth has become frozen during very severe winters. The latter is the depth of cover required in most large towns, but in Manchester 3 feet, and in Bradford 2 feet is adopted as the minimum.

In all systems of distribution it is not only of the highest importance to have all the mains of ample size, but that the service mains be so arranged that there shall be few or no "dead ends," and that, as far as possible, all valves and connections should be placed so that in case of accident to one main the supply may be kept up from another.

—The "dead end" system had many apparent advantages which caused it to be generally used. Parts of the system could easily be cut off when necessary by a single valve, and the sizes of the mains could be readily calculated. It was soon found, however, that the stagnant water in the ends became deteriorated in quality, and it has sometimes been suspected that where disease germs had gained access to the mains they had been able to multiply in the still water. This can in part be prevented by placing flushing valves at the ends of the mains, but these require constant attention, and if regularly opened cause the waste of much water. On the whole it seems preferable to adopt some form of interlacing system, in which the ends of the mains are connected together wherever possible. By a proper arrangement of sluices any small portion of the system can be cut off by closing two valves, whenever such closure is necessary for the repair of that portion. Formerly the supply to a district had to be stopped every time the main was being tapped, but ferrule machines have been constructed and are now largely used, which enables the "house service" mains to be attached to the service mains whilst the latter are full of water under pressure. Where this machine is used the occasions upon which it is

necessary to cut off any part of the system are very rare. It is obvious that water-waste preventors, such as Deacon's, cannot be used on any portion of the interlacing system. They must be attached to near the ends of the distributing mains, and each controlled by a valve beyond the meter, and there should be a separate distributing main for each district of from 2,000 to 5,000 people.

House service pipes may be of lead, tin-lined lead, tin-lined iron, cast iron or wrought iron, enamelled or galvanised.

Lead pipe is most generally applicable, but it should not be used with waters which contain very little or no carbonates. Such waters are usually very soft, but it is desirable to remember that occasionally very soft waters contain carbonate of soda and have no action on lead, and that hard waters sometimes are free from carbonates and then act upon this metal. To prevent this action tin-lined lead pipe was introduced, but has not answered the expectations of its makers. It possesses little advantage over lead pipe, and has many disadvantages, besides being much dearer. Still more recently a tin-lined iron pipe has been placed in the market, and so far as present experience enables its merits to be appraised, it would appear to possess many advantages over all other kinds of pipe. It consists of strong wrought-iron tube with an internal lining of block tin, and the lengths are joined up by screw joints, so that the tin lining is practically continuous.

Wrought-iron pipes are cheaper than lead, and as easily or more easily fitted, and admit of repairs and alterations being made with equal facility, provided double screw joints are used at convenient points. They are, however, very liable to become choked by internal corrosion. A pipe 1 inch in diameter may choke in from six to ten years. If galvanised its durability is much increased. Certain soft waters, however, possess the power of dissolv-

ing zinc, and of rapidly corroding the iron. In such a case the tin-lined iron pipe becomes indispensable, since the same waters invariably act upon lead.

Where water pipes have to be carried through made ground containing ashes, spent lime, chemical refuse, etc., they should be protected by a clay puddle, concrete, or asphalte covering, otherwise they will be injuriously affected.

To prevent the action of frost a minimum depth of 3 feet is desirable, and within the house they should be placed in positions in which the frost is least likely to affect them. No pipe will withstand the action of frost, but lead pipes may usually be frozen many times before actually bursting, on account of the ductility of the metal. The split caused by the expansion of the water in the act of freezing is in all cases longitudinal. In lead pipe the metal bulges before splitting. As it is of the highest importance for the prevention of waste and pollution that all house connections should be properly made, and the fittings be of a satisfactory character, the regulations made under the "Metropolis Water Act, 1871," as to house fittings, are given in an appendix, as upon them are based the regulations of many other towns.

Mr. T. Duncanson, in his paper, already referred to, on "The Distribution of Water Supplies," gives the following brief summary of the objects to be aimed at in providing a public supply of water:—

"(1) That a sufficient supply of wholesome water for the reasonable needs of a community should be provided.

"(2) That this water should be so supplied that at all times there is sufficient pressure to reach the highest part of every house.

"(3) That all piping and fittings should be of such a character and so arranged as to reduce the probability of failure to a minimum.

"(4) That there should be an effective system for the prompt detection of waste when it does occur.

"(5) That all arrangements should be of such a character as to reduce the inconvenience arising from necessity for repairs to a minimum.

"(6) That all appliances for the consumption of water should be so arranged as to use it in the most efficient way.

"The extent to which a public supply meets the above requirements will be a fair index of its character."

APPENDIX TO CHAPTER XXIII.

Regulations made under the Metropolis Water Act, 1871.

1. No "communication pipe" for the conveyance of water from the waterworks of the Company into any premises shall hereafter be laid until after the point or place at which such "communication pipe" is proposed to be brought into such premises shall have had the approval of the Company.

2. No lead pipe shall hereafter be laid or fixed in or about any premises for the conveyance of, or in connection with the water supplied by the Company (except when, and as otherwise authorised by these regulations, or by the Company), unless the same shall be of equal thickness throughout, and of at least the weight following, that is to say:—

Internal Diameter of Pipe in inches.	Weight of Pipe in pounds per lineal yard.
$\frac{3}{8}$ inch diameter	5 lb. per lineal yard
$\frac{1}{2}$ " "	6 " "
$\frac{5}{8}$ " "	$7\frac{1}{2}$ " "
$\frac{3}{4}$ " "	9 " "
1 " "	12 " "
$1\frac{1}{4}$ " "	16 " "

3. Every pipe hereafter laid or fixed in the interior of any dwelling-house for the conveyance of, or in connection with, the water of the Company, must, unless with the consent of the Company, if in contact with the ground, be of lead, but may otherwise be of lead, copper, or wrought iron, at the option of the consumer.

4. No house shall, unless with the permission of the Company in writing, be hereafter fitted with more than one "communication pipe."

5. Every house supplied with water by the Company (except in cases of stand pipes) shall have its own separate "communication pipe," provided that, as far as is consistent with the special Acts of the Company, in the case of a group or block of houses, the water-rates of which are paid by one owner, the said owner may, at his option, have one sufficient "communication pipe" for such group or block.

6. No house supplied with water by the Company shall have any connection with the pipes or other fittings of any other premises, except in the case of groups or blocks of houses, referred to in the preceding regulation.

7. The connection of every "communication pipe" with any pipe of the Company shall hereafter be made by means of a sound and suitable brass screwed ferrule or stop-cock with union, and such ferrule or stop-cock shall be so made as to have a clear area of water-way equal to that of a half-inch pipe. The connection of every "communication pipe" with the pipes of the Company shall be made by the Company's workmen, and the Company shall be paid in advance the reasonable costs and charges of, and incident to, the making of such connection.

8. Every "communication pipe" and every pipe external to the house, and through the external walls thereof, hereafter respectively laid or fixed in connection with the water of the Company, shall be of lead, and every joint thereof shall be of the kind called "plumbing" or "wiped" joint.

9. No pipe shall be used for the conveyance of, or in connection with, water supplied by the Company, which is laid or fixed through, in, or into any drain, ash-pit, sink, or manure-hole, or through, in, or into any place where the water conveyed through such pipe may be liable to become fouled, except where such drain, ash-pit, sink, or manure-hole, or any such place, shall be in the unavoidable course of such pipe, and then in every such case such pipe shall be passed through an exterior cast-iron pipe or jacket of sufficient length and strength, and of such construction as to afford due protection to the water pipe.

10. Every pipe hereafter laid for the conveyance of, or in connection with, water supplied by the Company, shall, when laid in open ground, be laid at least 2 feet 6 inches below the surface, and shall in every exposed situation be properly protected against the effects of frost.

11. No pipe for the conveyance of, or in connection with, water supplied by the Company, shall communicate with any cistern, butt, or other receptacle used or intended to be used for rain water.

12. Every "communication pipe" for the conveyance of water to

be supplied by the Company into any premises shall have at or near its point of entrance into such premises, and if desired by the consumer within such premises, a sound and suitable stop-valve of the screw-down kind, with an area of water-way not less than that of a half-inch pipe, and not greater than that of the "communication pipe," the size of the valve within these limits being at the option of the consumer. If placed in the ground such "stop-valve" shall be protected by a proper cover and "guard-box."

13. Every cistern used in connection with the water supplied by the Company shall be made and at all times maintained water-tight, and be properly covered and placed in such a position that it may be inspected and cleansed. Every such existing cistern, if not already provided with an efficient "ball-tap," and every such future cistern, shall be provided with a sound and suitable "ball-tap" of the valve kind for the inlet of water.

14. No overflow or waste pipe other than a "warning pipe" shall be attached to any cistern supplied with water by the Company, and every such overflow or waste pipe existing at the time when these regulations come into operation shall be removed, or at the option of the consumer shall be converted into an efficient "warning pipe," within two calendar months next after the Company shall have given to the occupier of, or left at the premises in which such cistern is situated, a notice in writing requiring such alteration to be made.

15. Every "warning pipe" shall be placed in such a situation as will admit of the discharge of the water from such "warning pipe" being readily ascertained by the officers of the Company. And the position of such "warning pipe" shall not be changed without previous notice to and approval by the Company.

16. No cistern buried or excavated in the ground shall be used for the storage or reception of water supplied by the Company, unless the use of such cistern shall be allowed in writing by the Company.

17. No wooden receptacle without a proper metallic lining shall be hereafter brought into use for the storage of any water supplied by the Company.

18. No draw-tap shall in future be fixed unless the same shall be sound and suitable and of the "screw-down" kind.

19. Every draw-tap in connection with any "stand pipe" or other apparatus outside any dwelling-house in a court or other public place, to supply any group or number of such dwelling-houses, shall be sound and suitable and of the "waste-preventer" kind, and be protected as far as possible from injury by frost, theft, or mischief.

20. Every boiler, urinal, and water-closet, in which water supplied by the Company is used (other than water-closets in which hand

flushing is employed), shall, within three months after these regulations come into operation, be served only through a cistern or service-box and without a stool-cock, and there shall be no direct communication from the pipes of the Company to any boiler, urinal, or water-closet.

21. Every water-closet cistern or water-closet service-box hereafter fitted or fixed, in which water supplied by the Company is to be used, shall have an efficient waste-preventing apparatus, so constructed as not to be capable of discharging more than two gallons of water at each flush.

22. Every urinal-cistern in which water supplied by the Company is used other than public urinal-cisterns, or cisterns having attached to them a self-closing apparatus, shall have an efficient "waste-preventing" apparatus, so constructed as not to be capable of discharging more than one gallon of water at each flush.

23. Every "down pipe" hereafter fixed for the discharge of water into the pan or basin of any water-closet shall have an internal diameter of not less than one inch and a quarter, and if of lead shall weigh not less than nine pounds to every lineal yard.

24. No pipe by which water is supplied by the Company to any water-closet shall communicate with any part of such water-closet, or with any apparatus connected therewith, except the service-cistern thereof.

25. No bath supplied with water by the Company shall have any overflow waste pipe, except it be so arranged as to act as a "warning pipe."

26. In every bath hereafter fitted or fixed the outlet shall be distinct from, and unconnected with, the inlet or inlets; and the inlet or inlets must be placed so that the orifice or orifices shall be above the highest water-level of the bath. The outlet of every such bath shall be provided with a perfectly water-tight plug, valve, or cock.

27. No alteration shall be made in any fittings in connection with the supply of water by the Company without two days' previous notice in writing to the Company.

28. Except with the written consent of the consumer, no cock, ferrule, joint, union, valve, or other fitting, in the course of any "communication pipe," shall have a water-way of less area than that of the "communication pipe," so that the water-way from the water in the district pipe or other supply pipe of the Company up to and through the stop-valve prescribed by Regulation No. 12, shall not in any part be of less area than that of the "communication pipe" itself, which pipe shall not be of less than a half-inch bore in all its courses.

29. All lead "warning pipes" and other lead pipes of which the

ends are open, so that such pipes cannot remain charged with water, may be of the following minimum weights, that is to say:—

½ inch (internal diameter)	. . .	3 lb. per yard.
¾ ,, ,,	. . .	5 lb. ,,
1 ,, ,,	. . .	7 lb. ,,

30. In these regulations the term "communication pipe" shall mean the pipe which extends from the district pipe or other supply pipe of the Company up to the "stop-valve" prescribed in the Regulation No. 12.

31. Every person who shall wilfully violate, refuse, or neglect to comply with, or shall wilfully do or cause to be done any act, matter, or thing, in contravention of these regulations, or any part thereof, shall, for every such offence, be liable to a penalty in a sum not exceeding £5.

32. Where, under the foregoing regulations, any act is required or authorised to be done by the Company, the same may be done on behalf of the Company by an authorised officer or servant of the Company, and where, under such regulations, any notice is required to be given by the Company, the same shall be sufficiently authenticated if it be signed by an authorised officer or servant of the Company.

33. All existing fittings, which shall be sound and efficient, and are not required to be moved or altered under these regulations shall be deemed to be "prescribed fittings" under the "Metropolis Water Act, 1871."

N.B.—Water is wasted in several ways, as by defective works and arrangements, by improper fittings, and by abuse and neglect; proper fittings, and sound workmanship will give good works a fair commencement, but subsequent inspection and repairs will be necessary so long as they are in use. It will be found by experience that it is cheaper to supervise and repair the mains and fittings, rather than to allow water to flow to waste.

CHAPTER XXIV.

THE LAW RELATING TO WATER SUPPLIES.

It generally happens that when a water supply is to be provided, land or water rights, or land and way leaves, have to be acquired. This may be done either voluntarily or compulsorily, the Public Health Act, 1875, section 175, providing that any Local Authority may purchase, take on lease, sell, or exchange any lands, whether situated within or without their district, and may also buy up any water-mill, dam, or weir which interferes with the proper drainage of, or the supply of water to, their district. It is desirable, if possible, to purchase voluntarily, as the expenses of acquiring land compulsorily are considerable, and add much to the cost, especially in the case of village water supplies. But it frequently happens that the necessary land can only be acquired by compulsory purchase, and to enable Local Authorities to purchase compulsorily, the Lands Clauses Consolidation Acts are, by section 176 of the Public Health Act, 1875, incorporated with that Act; and that section prescribes the course to be taken by a Local Authority before putting in force the powers of the Lands Clauses Acts as to purchasing and taking lands otherwise than by agreement.

The Lands Clauses Act, 1845, contains valuable powers, enabling tenants for life and other owners of limited estates to carry out voluntarily sales of the lands in which they are interested.

Many persons being incapacitated from selling their lands by reason of disabilities of various kinds, section 6

of that Act enables all parties entitled to any such lands, or any estate or interest therein, to sell and convey the same, and particularly for all Corporations, tenants in tail or for life, married women seised in their own right or entitled to dower, Guardians, Committees of Lunatics and of Idiots, Trustees or Feoffees in trust for charitable or other purposes, Executors and Administrators, and all parties for the time being entitled to the receipt of the rents and profits of any lands in possession, to sell the same.

Similar powers, enabling tenants for life and other persons having less than an absolute interest in lands to sell voluntarily, are conferred by the Settled Land Act, 1882, under sections 3 and 58 of which a tenant for life, tenant in tail, tenant by the courtesy, and other limited owners, may sell the settled land or any part thereof, or any easement, right, or privilege of any kind for or in relation to the land.

There is a prevalent idea that Local Authorities may use roadsides wastes for sinking wells and other water supply purposes; but this is erroneous. Local Authorities, as such, have no rights whatever in these wastes, and the law presumes, until evidence is given to the contrary, that the soil of the roadway to the middle of the road, and of the adjoining strip of waste belongs to the owner of the land adjoining to the highway or to the strip of waste; and the owner of the roadway and of the strip of waste is entitled to use his property in every way not inconsistent with the public right of passage, the right of the public merely extending to pass along the surface of the road, and for that purpose to keep it in repair.

This presumption as to the ownership of the soil of the roadway has been said to rest on the supposition that when the road was originally set out, the proprietors of the adjoining land each contributed a portion of their land

for its formation, and the presumption that the soil of a strip of land lying between the highway and the adjacent enclosure belongs to the owner of that enclosure is founded on the supposition that the proprietor of the adjoining land, at some former period, gave up to the public free passage of the land between his enclosure and the middle of the road, or, when enclosing his land for the road, he left an open space at the side of the road, over which the public might deviate if necessary, to avoid the liability to repair which would otherwise have fallen upon him. If the strip of land communicates with or is contiguous to an open common or large portion of land, the presumption is done away with or considerably narrowed, for the evidence of ownership which applies to the large portions applies also to the narrow strip which communicates with them.

Before proceeding to purchase lands, springs, or streams for water-supply purposes, precautions should be taken—

(*a*) To ascertain whether and to what extent neighbouring landowners can prevent, by legal proceedings, the water yielded therefrom being used for the proposed water-supply purposes.

(*b*) Whether and to what extent such landowners can, by digging wells, cutting trenches, or executing other works on their own lands, abstract or divert the water proposed to be utilised.

As to the first question—As a general rule every landowner (including a Local Authority owning land) has the right to dig wells and execute other works on his land, and thus obtain or divert for his own purposes as much of the water flowing under his land as he can, even though the effect may be to abstract or divert the underground waters which otherwise would flow to and become feeders of springs and streams on other property. But the law is different with regard to a watercourse, which has been defined by Lord Tenterden as "water flowing in a channel between banks more or less defined."

The riparian proprietors whose lands adjoin a watercourse may take water from it, but in doing so must have due regard to the similar rights of others whose lands adjoin the stream, and who have the right "to have the watercourse or stream come to them in its natural state in flow, quality, and quantity."

A spring and a stream have been thus defined by Jessel, M.R.—"A spring of water is, as I understand it, a natural source of water, of a definite and well-marked extent. A stream of water is water which runs in a defined course, so as to be capable of diversion, and it has been held that the term does not include the percolation of underground water." What is a stream, and where does it begin? is a question which was raised in the case of Dudden *v.* Guardians of the Clutton Union, reported in 11 Exchequer Reports, 627, and 26 Law Journal Reports, Exchequer, 146, where the plaintiff was the owner of an ancient mill which was supplied with water from a brook. Adjoining this brook was a spring, the water from which flowed by a natural channel into the brook. The guardians, for the purpose of supplying the workhouse with water, placed tanks and pipes close to the spring-head, and took the water before it flowed into the natural channel. The judge directed the jury to find for the plaintiff (and they did so) if they thought the water flowed in a defined regular course from the spring-head to the brook.

Upon the application to the Court to set aside the verdict, Baron Martin thus stated the law:—"The right to flowing water is a natural right, and all parties are entitled to the use of it, but a party would not be entitled to divert it when it is in the act of springing from the ground. He cannot legally prevent its flowing into its natural channel." And Baron Watson added, "If the diversion in this case had taken place ten yards from the spring-head, there would be no doubt in the case, and the rule is the same if the water is diverted at the source."

The law respecting the right to water flowing in definite visible channels is clearly enunciated by the judgment of the Court of Exchequer in the case of Embrey *v.* Owen, reported in 6 Exchequer Reports, 353, and 20 Law Journal Reports, E. 212.

This case decided that water is *publici juris* in this sense only, that all may reasonably use it who have the right of access to it. No man can have any property in the water itself, except in that particular portion which he may choose to abstract from the stream and take into his own possession, and that during the time of his possession only. Also that the proprietor of the adjacent land has the right to the usufruct of the streams that flow through it, not as an absolute and exclusive right to the flow of all the water in its natural state, but subject to the similar rights of all proprietors of the banks on each side to a reasonable enjoyment thereof.

In the case of Milner *v.* Gilmour, Lord Kingsdown laid down the law as to running streams as follows:—"By the general law applicable to a running stream, every riparian proprietor has a right to what may be called the ordinary use of the water flowing past his land, for instance to the reasonable use of the water for his domestic purposes and for his cattle, and this without regard to the effect which such use may have in case of deficiency upon proprietors lower down the stream; but further he has a right to the use of it for any purpose, or what may be termed the extraordinary use of it, provided that he does not thereby interfere with the rights of other proprietors either above or below him. Subject to this condition he may dam it for the purposes of a mill, or divert the water for the purpose of irrigation, but he has no right to interrupt the regular flow of the stream if he thereby interferes with the lawful use of the water by other proprietors, and inflicts upon them a sensible injury." Such extraordinary use, in order to be justifiable, must, however, be a reasonable one,

and one for which a riparian proprietor is entitled to take the water from its natural course; for where an unreasonable use is made of the water by one riparian proprietor, the others are entitled to have it restrained, even though they prove no actual damage, on the ground that it is an interference with a right which, unless restrained, would in the course of twenty years confer on the claimant a right of prescription in derogation of the prior right. It would appear from the case of the Swindon Water Co. *v.* Wilts and Berks Canal (Law Reports, 9 Ch. 457), that an "extraordinary use," as well as being reasonable, must be for the use of the riparian tenement.

But the law as laid down in these cases is inapplicable to the case of subterranean water not flowing in any separate channel, or flowing indeed at all in the ordinary sense, but percolating or oozing through the soil, more or less according to the quantity of rain that may chance to fall.

The case of Broadbent *v.* Ramsbotham, reported in 11 Exchequer Reports, 611, and 26 Law Journal Reports, Ex. 115, decided that the right of a riparian owner to the lateral tributaries or feeders of the main stream applies to waters flowing in a defined and natural channel or water-course, and does not extend to water flowing over, or soaking through, previous to its arrival at such water-course.

In this case it was decided that the plaintiff, who was a millowner, having the right to use the water of a natural stream, called Longwood brook, had no cause of action against the owners of adjacent land for diverting water, which, coming from a pond formed by landslips, escaped over the surface of this land, and thence, by natural force of gravity, found its way by land-drains or dykes to the brook; or for diverting the overflow from a well and a swamp on that land, which ran in wet seasons to the brook; or for diverting the overflow from another well on that land used as a watering-place for cattle, which overflow

formed a stream, and, after following the course of an artificial ditch, along a hedge-side, and in other parts flowing down a small channel, formed by the water, and over swampy places, where the cattle had trodden in the soil, ran over a field, and thence along a natural valley, and along hedge-sides and ditches, and discharged itself into the brook; and it was held that the plaintiff, although he had a right to the use of the water of the brook, had no cause of action against the owner of the adjacent land for diverting either of the above three sources of supply before the waters had arrived at a definite natural watercourse.

With regard to the second question, the law has been defined and settled by two important decisions of the House of Lords, the first of Chasemore *v.* Richards, decided in July, 1859, and reported in 7 House of Lords Reports, 382, and 29 Law Journal Reports, Exchequer, 81, which decided that the owner of land, containing underground water which percolates by undefined channels, and flows to the land of a neighbour, has the right to divert or appropriate the percolating water within his own land, so as to deprive his neighbour of it.

In that case, much of the law relating to waters flowing above or underground was dealt with by the various learned judges who delivered judgments. The facts of the case and the law relating to it were stated by Mr. Justice Wightman as follows:—

"The plaintiff is the occupier of an ancient mill on the river Wandle, and for more than sixty years he and his predecessors had used and enjoyed, as of right, the flow of the river for the purposes of working their mill; the river had always been supplied above the plaintiff's mill, in part, by the water produced by the rainfall on a district of many thousand acres in extent, comprising the town of Croydon and its vicinity. The water of the rainfall sinks into the ground to various depths, and then flows and percolates through the strata to the river Wandle, part rising to the

surface, and part finding its way underground in courses which continually vary.

"The Croydon Local Board sink a well in their own land in the town of Croydon, and by means of the well and by pumping from it large quantities of water for the supply of the town of Croydon, the Board abstracted and interrupted underground water (but underground water only) that otherwise would have flowed and found its way into the river Wandle, and so to the plaintiff's mill, and the quantity so diverted was sufficient to be of sensible value toward working the mill."

The law as decided in Chasemore *v.* Richards has been followed and extended by the important recent case, decided by the House of Lords in July, 1895, of the Mayor, Aldermen, and Burgesses of the Borough of Bradford *v.* Edward Pickles, where it was decided that not only has the owner of land containing underground water which percolates by undefined channels and flows to the land of his neighbour the right to divert or appropriate the percolating water within his own land so as to deprive his neighbour of it, but his right to do this is the same whatever his motive may be, whether to improve his own land or maliciously to injure his neighbour or to induce his neighbour to buy him out. In this case the Corporation of Bradford were the owners of Trooper Farm and certain springs and streams rising in or flowing through that farm, which were purchased many years ago by the Bradford Waterworks Company, and from which the Corporation obtained a valuable supply of water for the domestic use of the inhabitants of Bradford. In 1892 the respondent Pickles began to sink a shaft on his land adjoining Trooper Farm, and also to drive a level through his land for the professed purpose of draining the strata with the view to the working of his minerals. These operations had the effect of diminishing the water supply obtainable from the springs on Trooper Farm. The Corporation of Bradford

brought this action to restrain the defendant Pickles from continuing to sink the shaft or drive the level, and from doing anything whereby the waters of the spring and the stream might be drained off or diminished in quantity. Lord Halsbury, in delivering judgment, said: "The acts done or said to be done by the defendant were all done upon his own land, and the interference, whatever it is, with the flow of water is an interference with water which is underground and not shown to be water flowing in any defined stream, but is percolating water which, but for such interference, would undoubtedly reach the plaintiffs' waterworks, and in that sense it has deprived them of the water which they would otherwise get; but although it has deprived them of water which they would otherwise get, it is necessary for the plaintiffs to establish that they have a right to the flow of water, and that the defendant has no right to do what he is doing. I am of opinion that the question whether the plaintiffs have a right to the flow of such water is covered by the decision in the case of Chasemore *v.* Richards. The very question was then determined by this House, and it was held that the landowner has a right to do what he had done, whatever his object or purpose might be, and although the purpose might be wholly unconnected with the enjoyment of his own estate."

In delivering his judgment, Lord Macnaughten stated: "The position of the appellants is one which it is not easy to understand. They cannot dispute the law laid down by this House in Chasemore *v.* Richards. They do not suggest that the underground water with which Mr. Pickles proposes to deal flows in any defined channel. But they say that Mr. Pickles' action in the matter is malicious, and that, because his motive is a bad one, he is not at liberty to do a thing which every landowner may do with impunity if his motives are good. It may be taken that his real object was to show that he was the master of the situation,

and to force the Corporation to buy him out at a price satisfactory to himself. Well, he has something to sell, or, at any rate, he has something which he can prevent other people enjoying without paying for it. Why should he, he may think, without fee or reward, keep his land as a storeroom for a commodity which the Corporation dispense, probably not gratuitously, to the inhabitants of Bradford? He prefers his own interests to the public good. He may be churlish, selfish, and grasping. But where is the impulse? Mr. Pickles has no spite against the people of Bradford. He bears no ill-will to the Corporation. They are welcome to the water, and to his land too, if they will pay the price for it. So much, perhaps, might be said in defence, or in palliation of Mr. Pickles' conduct, but the real answer to the claim of the Corporation is that in such a case motives are immaterial. It is the act, not the motive for the act, that must be regarded. If the act, apart from the motive, gives rise merely to damage without legal injury, the motive, however reprehensible it may be, will not apply without element."

Since the last edition of this book was written a further interesting case on the rights to underground water has arisen and been decided by the Court of Appeal. The case is reported in the Law Reports, 1899, 2 Chan., p. 217, Jordeson *v.* Sutton, Southcoates and Dryport Gas Company. The head note to the case is as follows: "The plaintiff was the owner of land with houses on it, and the adjoining land belonged to the defendants, a Gas Company, incorporated by special Act, with power to purchase land by agreement only, and subject to the provisions of the Gas Works Clauses Acts, 1847 and 1871. The Company proceeded to excavate their land for the purpose of erecting a gasometer. In so doing they penetrated an underground stratum of quicksand, or sand loaded with water, geologically know as 'running silt,' which extended under the plaintiff's land as well as their own, the land largely

preponderating over the water. In draining their excavation the defendants withdrew a large quantity of the running silt from under the plaintiff's land, and thus caused a subsidence of the surface with consequent structural injury to his houses. It was held by the Court of Appeal (Lindley, M.R., and Rigby, L.J.) that the plaintiff's land was supported, not by a stratum of water but by a bed of wet sand or running silt; and that as the defendants had caused the subsidence by withdrawing this support they had committed an actionable nuisance at Common Law, entitling the plaintiff to damages; but Vaughan-Williams, L.J., held that the subsidence had been caused by the withdrawal through the defendants draining operations on their own land of subterranean water support of the plaintiff's land, and that on the authority of Popplewell *v.* Hodkinson, L.R. 4 Ex. 288, the withdrawal of subterranean *water* support from a neighbour's land in the course of draining one's own land gives him no cause of action."

So, as the law now stands (the decision of the majority of the Court of Appeal standing) in any draining or drawing of water operations, care must be taken to draw nothing but water, or at all events only to a small extent, for if any quantity of silt or sand is drawn with the water and damage is sustained, the withdrawer of the water will be liable for such damage; but if only water is drawn, then, though he may do a considerable amount of damage, until this decision is in effect reversed by a decision of the House of Lords, or until some Act of Parliament is passed further defining the rights to underground water, he cannot be mulct in damages.

Popplewell *v.* Hodkinson, which was a case of appeal from the old Court of Exchequer, held that an owner of land has no right at Common Law to the support of subterranean water.

The law as to the making and recovery of water-rates

and water-rents is much in need of consolidation and amendment. The Waterworks Clauses Act, 1863, and certain provisions of the Waterworks Clauses Act, 1847, are incorporated with the Public Health Act, 1875, and the following clauses of the 1847 Act may be referred to, as to water-rates and water-rents:—

"Secs. 48 to 52. Any owner or occupier of a dwelling-house may open ground, and lay communication or service pipes to connect house with mains, under certain conditions.

"Sec. 53. Every owner and occupier, when he has laid such communication pipes and paid the water-rate, is entitled to a sufficient supply of water for domestic purposes.

"Sec. 68. Water-rates (except as in sec. 72) are to be paid by the person receiving or using the supply of water, and to be payable according to the annual value of the tenement supplied, any dispute arising as to such value to be settled by two justices.

"Sec. 69. When several houses, or parts of houses in the separate occupations of several persons, are supplied by one common pipe, the several owners or occupiers are liable to the payment of the same water-rates as if each were supplied by a separate pipe.

"Sec. 70. Water-rates to be paid in advance, by equal quarterly payments, at Christmas Day, Lady Day, Midsummer Day, and Michaelmas Day.

"Sec. 72. The owners of all dwelling-houses or separate tenements, the annual value of which does not exceed £10, are liable to payment of the water-rates instead of the occupiers."

To make the owner or occupier liable, it is not necessary that the water should be laid on to the house, section 9 of the Public Health Water Act, 1878, enacting that where a stand pipe has been provided water-rates or water-rents may be recovered from the owner or occupier of every dwelling-house within 200 feet of any such stand pipe,

in the same manner as if the supply had been given on the premises. But if such dwelling-house has within a reasonable distance, and from other sources, a supply of wholesome water sufficient for the consumption and use of the inmates, no water-rate or water-rent is recoverable from the owner or occupier until the water supplied from the stand pipes is used by the inmates of the house. This section applies to rural districts only.

Where stand pipes are used questions are often raised by householders, who seem to object to water-rates, even more than to other rates, on the ground that their houses are provided with water from some ancient well, or other source. A little patience is generally not wasted on them, for if left alone they soon find the use of the water from the stand pipe to be so great a convenience that they take to using it, and then pay the water-rates with as good grace as they do other rates. In some cases, however, where a water-rate hater insists on continuing to use water from some polluted well or other source, it becomes necessary to compel him to pay the water-rate, even though he does not use the water from the stand pipe, on the ground that his supply is not wholesome. When compelled to pay the rate he will soon begin to use the water, to get over his objection to being made to pay for what he does not use.

"Sec. 74. If a person liable to pay water-rates neglects to do so, water may be cut off, and water-rates and expenses of cutting off the water recovered in manner mentioned in the section."

Objection is often made that the incidence of a water-rate is unfair, because, assuming the water-rate to be 1s. in the £1, one occupier of a house rated at, say, £15, and using very little water, pays as much for his water-rate as another neighbouring occupier of a similarly-rated house, or house and shop, possibly using many times as much water as his neighbour. This may be often so, for the quantity used

will depend on the number and habits of the household, and whether baths and water-closets are used or not; but section 12 of the Waterworks Clauses Act, 1863, provides that a supply of water for domestic purposes is not to include a supply of water for cattle or for horses, or for washing carriages, where kept for sale or hire, or by a common carrier, or a supply for any trade, manufacture, or business, or for watering gardens, or for fountains, or for any ornamental purpose.

Where water is used for flushing sewers, road watering, etc., a charge should be made on the general district rate for the water so used. In some districts the rates paid by the users of the water cover not only the annual repayment of the loan, with interest, but also the cost of maintenance. In this case the tenants or owners of the property pay for the waterworks in the course of a term of years, at the end of which they are the absolute property of the L.A., and not of those who have paid for them. In other cases the water-rates only cover the interest and cost of maintenance, the principal being paid off from the general district rate. This seems a perfectly fair arrangement, as the works ultimately become the property of the L.A., which has paid for them. In other instances the sum to be paid by the users of the water is fixed in an arbitrary manner, and the balance raised from the general district rate. The mode in which the cost of public supplies is met, in different districts, is referred to in the subjoined chapter on rural water supplies.

Up to the passing of the Local Government Act, 1894, the Rural Sanitary Authority was, under the Public Health Act, 1875, the only body having power to provide water-supply works in rural parishes; but under section 8 of the 1894 Act a Parish Council has power to utilise any well, spring, or stream, within their parish, and provide facilities for obtaining water therefrom, but so as not to interfere with the rights of any corporation or person;

and the Parish Council have power also under the same section to contribute towards the expense of doing this, or to concur or combine with any other Parish Council to do so, or contribute towards the expense of such water supply. It is probable that these powers will be seldom used, because the Rural District Councils have already full power to provide water supplies for any parish in their districts, the expense of so doing being a special charge upon that parish; and it is provided in section 8 that nothing contained in that section shall derogate from the obligation of the District Council with respect to the supply of water; also that Parish Councils are not to acquire, otherwise than by agreement, any land for the purpose of any water supply. The 1894 Act, however, contains useful provisions for the protection of these councils, with regard to the action of the Rural District Councils as to water supply, section 16 providing that where the Rural District Council has determined to adopt plans for the water supply of any parish, it shall give notice thereof to the Parish Council of the parish for which the works are to be provided, before any contract is entered into for carrying out the works. Also that where a Parish Council has resolved that a Rural District Council ought to have provided the parish with a supply of water, in case where danger arises to the health of the inhabitants from the insufficiency or unwholesomeness of the supply of water, and a proper supply can be obtained at a reasonable cost, the Parish Council may complain to the County Council, who, if satisfied that the District Council has so failed, may resolve that the duties and powers of the District Council, for the purpose of the matter complained of, shall be transferred to the County Council, and they shall be transferred accordingly; or instead thereof may make a similar order to that mentioned in section 299 of the Public Health Act, 1875, and appoint a person to perform the duty of providing the district with a water supply.

Before giving details of schemes which have been selected as typical, it may be well to mention categorically the more important clauses of certain Acts of Parliament bearing upon the provision of water supplies by Sanitary Authorities, some of which have already been referred to.

The Acts more particularly applying to water supplies are, the Public Health Act, 1875, clauses 51 to 70 inclusive; and the Public Health (Water) Act, 1878. In the following paragraphs the former will be referred to as the P.H.A., and the latter as the P.H.W.A.; the No. of the section will be placed in brackets, and L.A. will signify the Local Sanitary Authority.

P.H.A. (64). By this clause all existing public cisterns, pumps, wells, reservoirs, conduits, aqueducts, and works are vested in and under the control of the L.A.

Where a spring or other source of water is vested in the L.A., and can be utilised for a public supply, there are no water rights to purchase.

P.H.A. (51). The L.A. may provide their district, or any portion of their district, with a supply of water, and for this purpose may (*a*) construct waterworks, dig wells, etc.; (*b*) lease, or hire, or purchase waterworks; or (*c*) contract with any person for a supply of water.

P.H.A. (54). The L.A. have the same powers, etc., for carrying water mains as they have for carrying sewers.

P.H.A. (299-301). If a L.A. neglects to supply any portion of its district with wholesome water, where the present supply is a danger to health on account of its insufficiency or unwholesomeness, and a proper supply can be obtained at a reasonable cost, complaint may be made to the Local Government Board by any person, and the Local Government Board may order the L.A. to provide a supply.

P.H.A. (56 and 58). The L.A. may charge water-rates, or supply the water by meter, or may make special agreements with the person receiving the supply.

P.H.A. (61). Any L.A. may supply water to an adjoining district, with the consent of the Local Government Board.

P.H.A. (62). Where the Surveyor to the L.A. reports that any house within the district is without a proper supply of water, and that a supply can be had at a reasonable cost, the L.A. may compel the owner to provide a supply. If he makes default the L.A. may execute the works, and either recover the expenses in a summary manner, or may levy a rate on the premises.

P.H.A. (70). The L.A. may apply to a court of summary jurisdiction for an order to close any well, tank, or cistern, public or private, which is reported to be so polluted as to be injurious to health.

P.H.W.A. (3). It is the duty of every Rural Sanitary Authority to see that every occupied dwelling-house has a proper supply of water. A portion of this clause resembles that of the P.H.A. (62), but is less ambiguous in its wording, and the Medical Officer of Health or Sanitary Inspector is empowered to report, and not the Surveyor. By a reasonable cost is meant a sum of £8 13s. 4d., the interest of which, at 5 per cent. per annum, is 2d. per week; or, on the application of the L.A., such other cost not exceeding a capital sum (£13), the interest on which, at the rate of 5 per cent. per annum, would amount to 3d. per week. The owner may object on various grounds, one of which is that the L.A. ought themselves to provide a supply of water for the district, or the portion thereof in which the house is situated.

P.H.W.A. (6). No new house shall be inhabited until a certificate has been obtained from the L.A. to the effect that it has, "within a reasonable distance, such an available supply of wholesome water as may appear to such Authority, on the report of their Inspector of Nuisances or of their Medical Officer of Health, to be

sufficient for the consumption and use for domestic purposes of the inmates of the house."

One of the effects of this clause has already been referred to. Another is that, where the clause is enforced, new houses cannot be built to replace the old ones, in those districts where a water supply cannot be obtained at a "reasonable" cost, because water certificates will not be granted. The inhabitants, therefore, must continue to tenant the old cottages, however dilapidated, unless the latter be condemned. In such cases the L.A. must either provide a public supply, and so enable new cottages to be erected, or the people must be allowed to tenant the old places, or be turned out to find homes elsewhere.

P.H.W.A.* (9). Where the L.A. provide stand pipes they may recover water-rates or water-rents from the owners or occupiers of every dwelling-house within 200 feet of the stand pipe, unless such house has a good supply of its own.

The L.A., therefore, can provide stand pipes, and charge rates on all the houses using the water within 200 feet of each. Houses beyond this distance cannot be rated. In one of my districts numerous stand pipes are provided, and the owners need not lay on the water to the houses. In another, stand pipes are only provided under exceptional circumstances, and, wherever possible, the owners are compelled to lay on the water to the houses. By carrying a service main within 200 feet of a house not having a proper supply of water, and fixing a stand pipe, the house can be rated.

P.H.W.A. (8). Upon application to the Local Government Board, the Board may fix a general scale of charges, instead of the fixed charge referred to in (3).

The "Limited Owners Reservoirs and Water Supply Further Facilities Act, 1877," enables a landowner to charge his estate with the cost of constructing works for

* This section applies to Rural Sanitary Authorities only.

the supply of water thereto, or he may enter into an agreement with the L.A. or any company or person for the supply of water for any term not exceeding the number of years during which the cost of the improvement is a charge on the estate.

The following sections are from the Water Works Clauses Acts of 1847 and 1863:—

(1847 Act.) Sec. 44. Requires the L.A. to lay down communication pipes, etc., to any dwelling-house (under £10 rental) situate in any street where they have laid pipes, (1) either at the request of the owner, or (2) at the request of the occupier, upon payment or tender of the water-rate in respect of such house, by this Act made payable in advance.

Sec. 46. The L.A. are at liberty, on refusal to pay for water, to remove pipes and recover expenses.

Sec. 58. Imposes a penalty on occupiers or owners of premises permitting people who are not entitled to a supply of water to take water from their pipes.

Sec. 59. Any person taking water without right is liable to a penalty of £10.

Sec. 60. Any person wilfully injuring any lock, cock, valve, etc., is liable to a penalty.

(1863 Act.) Sec. 12. A supply of water for domestic purposes shall not include a supply for cattle, or for horses, or for washing carriages, where such horses or carriages are kept for sale or hire, or a supply for any trade, manufacture, or business, or for watering gardens, or for fountains, or for any ornamental purposes.

Secs. 17 to 19. Impose penalties for waste or misuse of water or for unauthorised alteration of service pipes.

The *Justice of the Peace* of 8th June, 1895, commenting on the provisions of the Public Health Act, 1875, as affecting water supplies, says: "Turning now to the provisions of the Public Health Act, we find there a code of rules regulating the manner in which a water

supply is to be carried on by the District Council. We do not intend to go through the sections, but only to call attention to one or two matters as affected by recent decisions. An interesting case arose under section 64 of the Public Health Act, 1875—the case of Holmfirth Local Board *v.* Shore—which we reported in last week's issue, *ante*, p. 344. By that section, all existing public cisterns, pumps, wells, reservoirs, conduits, aqueducts, and works used for the gratuitous supply of water to the inhabitants of the district of any Local Authority, are to vest in and be under the control of such Authority. In the Holmfirth case, it appeared that at Holmfirth there was, near the top of a hill, a well called Flacketer Well, supplied by a natural spring of water, flowing into a trough or cistern, and the overflow ran down the hill to another well or trough, or cistern of stone, called Ing Head Well or Trough. It was the Ing Head Well that was the subject of the litigation. The overflow from this place ran down the hill to a third well or trough or cistern in South Lane. It was in evidence that the Ing Head Well had been used by the neighbouring inhabitants for drawing water for domestic purposes, and for watering cattle, without any interference or opposition from any one for more than fifty years. Prior to the existence of the Plaintiff Authority, the district in which Ing Head Well was situated had been under the Wooldale Local Board, and that Board had laid pot pipes instead of a brick rubble drain from Flacketer Well all the way to South Lane. The Wooldale Local Board and other Local Authorities subsequently amalgamated, and formed the present Authority. In 1884 the defendant, who occupied a house near Ing Head Well, put up a gate to keep cattle away from it, and began to try to prevent the public from using it. Subsequently, he put a pipe in the bottom of the trough, leading into his own house, where it terminated in a stopcock, and by means of this pipe

and stopcock he could draw off all the water in the trough, or as much as he pleased. Among the defences set up before the County Court Judge was the defence that a trough was not a well at all, nor anything else mentioned in section 64. But the County Court Judge found as a fact that it was a well within the meaning of the section. On the question whether it vested in the Plaintiff Authority within the meaning of the sections, he also found that it did. These findings were seriously contested in the Divisional Court, but the appeal failed. Day, J., said: 'After looking at the photograph, I have come to the conclusion that this is not a "well," but a "public cistern, reservoir, conduit, or aqueduct," or certainly a "work used for the gratuitous supply of water," within the meaning of section 64 of the Public Health Act, 1875, and I cannot find any fault with the decision of the learned County Court Judge that it comes under one or other of these descriptions.' Wright, J., on the question of the 'well' vesting in the Local Authority, said: 'The leading authority, so far as I know, for construing those words, "vest in and be under the control of," as regards streets, is now the case of Wandsworth Board of Works *v.* United Telephone Company, 48 J. P. 676, and it seems to me to be applicable to wells as well as to streets. Looking at that, and the other cases as to streets, it seems to me now impossible to deny that the Local Authority have, in respect of the streets and wells vested in them by force of the statute, a right of property—not an absolutely unqualified right of property, but one capable of limitation in point of time, and limited in some respects as regards user—but still a right of property and of possession which is sufficient to enable them to complain of anything that interferes at all, not merely that injuriously interferes, with their occupation of the street or well for the purposes for which it is vested in them by the statute. Now, certainly, the boring of a hole at the

bottom of a cistern or well must interfere, whether injuriously or not, with the possession of it as a cistern or well. Therefore, on that point, the judgment of the learned County Court Judge was right.'

"A similar question arose under the Public Health (Scotland) Act, 1867. By section 89 (4) of that Act 'the Local Authority may cause all existing public cisterns, pumps, wells, reservoirs, conduits, aqueducts, and works used for the gratuitous supply of water to the inhabitants to be continued, maintained, and plentifully supplied with water.' It will be observed that the 'wells' do not vest in the Local Authority; it merely enables the Local Authority to cause them to be maintained. In Smith *v.* Archibald, 5 App. Cas. 489, the alleged rights of the owner and the rights of the Local Authority came in dispute. It appeared that there was a well in the corner of a private field. A footpath ran from the road to the entrance of the field, and a cart-road from this entrance to the public road, going through the village of Denny. The inhabitants of this village had for a prescriptive period used the water of the well for domestic purposes, and had had the well cradled with stones at their own expense. The Local Authority caused the well to be covered in with an iron plate, and placed therein a hand pump with the avowed object of keeping the well free from pollution. The proprietor of the field claimed the well as his private property, and instituted proceedings to have the cover and pump removed. The House of Lords held that the well was a public well within the meaning of section 89 (4), *supra*, and the Local Authority had not done anything in excess of their powers."

CHAPTER XXV.

RURAL AND VILLAGE WATER SUPPLIES.

PROBABLY every centre of population in the United Kingdom which aspires to the dignity of being called a town has, at the present time, some form of waterworks, of a more or less satisfactory character, supplying water by means of mains for the use of the inhabitants. For certain reasons it has been assumed that villages and hamlets and rural districts generally could not be so supplied, and the conditions as to water supply continue much as they have been from time immemorial. In rural districts, especially of an agricultural character, the inhabitants are very conservative in character, too prone to be satisfied with things as they are, and too lethargic to strongly desire or to express a desire for change, especially if such change will throw any additional burden on the rates. What was good enough for their forefathers is good enough for them. They have grown up under conditions to which they have become accustomed, and their exceedingly limited experience of other conditions does not enable them to comprehend the advantages which may be derived from a change. Where a public supply has been introduced into a village, it has frequently been as the result of an outbreak of some disease, an epidemic which, in all probability, would have been avoided had a proper supply been obtained earlier. In rural districts also the population is scattered. A parish may contain a fairly compact village, or it may contain one or more groups of

houses which may be called hamlets, or the cottages may be scattered over the whole area. In any case, to supply a given number of houses much longer mains are required than in a town, and the cost of obtaining a public supply is proportionately increased. Again, the wages earned in the country are much lower than in the towns, and the poorer classes are the less able to bear any additional burden in the form of rates. Unfortunately, also, landowners and property owners generally are affected by the depressed state of agriculture, and do not look with favour upon any scheme which, however much it may benefit the inhabitants, will not apparently confer any immediate benefit upon themselves, or an advantage in their opinion not commensurate with the expense they will have to bear. Still another difficulty arises from the fact that under the Public Health (Water) Act, 1878, no newly-erected house can be inhabited without the Sanitary Authority having certified that there is within a reasonable distance an available supply of wholesome water. There is no definition of the words "reasonable distance," "available supply," and "wholesome," and they are very differently interpreted by different authorities. By some, a quarter of a mile is considered a "reasonable distance," a water obtained on sufferance from a neighbour's property is considered "available," and tank water, pond, or even ditch water is considered "wholesome." A well water is almost invariably considered to be good whatever its source or the character of the surroundings of the well. In growing villages, therefore, we have often a large proportion of the houses rejoicing in the possession of these certificates, and if the Authority or its officers propose a public supply they are forthwith produced to prove that such is not required. If an owner has really been put to considerable expense to obtain a reasonably good water, it seems somewhat unjust that he should afterwards be called upon to contribute towards a similar

benefit being conferred upon the tenants of other properties, whose owners have failed to obtain such a supply. In rural districts, also, the officers employed rarely receive such remuneration as secures the services of men with wide experience, capable of working out the details of a waterworks scheme, and presenting it to the Authority so as to show its feasibility and convince them of its great advantages or of its necessity. Unless they are able to do this there is little likelihood of public water supplies being generally adopted in our villages and rural districts. The initial expense of calling in an engineer will have to be borne by the general rates unless a scheme be ultimately accepted and carried out. At this stage it may be doubtful whether it is possible to obtain a supply at a reasonable cost, and the Authority naturally hesitates at incurring this expense. I am perfectly convinced that none of the parishes in my districts, which are now enjoying all the advantages of having water mains ramifying in their midst, would ever have been so supplied had not the Surveyor been able to draw up all the details of the various schemes, prepare the plans, and superintend the carrying out of the works. Confidence engendered by the successful execution of one scheme, and the ultimate expressions of appreciation by those who at first opposed the innovation (for these are usually the first to acknowledge its advantages), pave the way for further extensions, and make each successive step in the march of sanitary progress less difficult.

That the water supplies of our parishes, derived from shallow wells, pools, ponds, land springs, rain-water tanks, or the hawker's cart, are often miserably inadequate in quantity, and most unsatisfactory in quality, requires no proof beyond that already given in preceding chapters of this work. Neither is it necessary to dwell upon the advantages of having an abundant supply of pure water which can be drawn from the tap at the very door, or,

better still, within the house, so conducing to the cleanliness of person, cleanliness of the household, and of the parish generally. Cleanliness may not be next to godliness, but its importance in maintaining health and vigour is too well established to need further demonstration. It is much to be regretted that whilst this is universally admitted with reference to man, it still appears to be entirely ignored with regard to cattle. Yet, the vital processes in the one are so closely akin to those in the other that it does not admit of reasonable doubt that all the conditions which make for health in the one are necessary for the other. Of especial importance to us, however, is cleanliness in connection with milch cows and dairy farms, since in this country it is almost universal custom to consume the milk raw. Milk contains all the necessary ingredients for supporting life; not only the life of the higher types of the animal kingdom, but also that of those lowest forms, be they animal or vegetable, the so-called microbes, many of which, when they gain access to the human system, are capable of producing disease. Some of these multiply with extraordinary rapidity when introduced into milk, and alarming outbreaks of disease have been traced to such infected milk. There is little doubt that many of these epidemics could have been prevented had the cattle been supplied with more wholesome water, had the milk-cans been cleansed with pure water, and had the teats of the cows and the milker's hands been clean. The importance of an abundant supply of pure water for dairies and dairy-farms is an additional argument in favour of public rural supplies.

Where water mains are laid in rural districts, the erection of cottages and houses is encouraged, since the owners are no longer under the necessity of sinking wells, constructing rain-water tanks, fixing pumps, etc., with their initial expense and perpetual trouble to keep in repair. Very often the interest on the original expendi-

ture for a well and pump exceeds that of the water rate which would suffice to pay for a public supply.

The difficulties in the way of supplying thinly-populated areas with water have been greatly overrated, and probably in few cases are they insurmountable. In recommending a really good scheme, one can always feel the utmost confidence in asserting that, however much it may be opposed by those intended to be benefited, and local opposition always arises when a Sanitary Authority decides to provide waterworks, the works will not be in existence long before the growlings are replaced by grateful acknowledgments of the boon conferred. Simple and inexpensive supplies can often be obtained by collecting the water from a spring, and laying mains from the reservoir or tank to hydrants along the route. Where pumping is necessary the motive power may often be obtained by aid of a ram, turbine, or water-wheel, at a reasonable initial expense, and at a cost of very few shillings per year for attention and repairs. If these machines cannot be utilised, a windmill may be employed; although, on account of the large size of the storage tank necessary, the expense in the first instance will be somewhat greater. Gas, oil, and hot-air engines also require but little attention, and only such as can be given by an intelligent labourer. The weekly labour bill, however, is an important item when the works are small, but sometimes a supply of water near at hand can be utilised by pumping with one of these machines, whereas the nearest source available for working a ram or similar machine may be a considerable distance away. In such a case the cost of pumping may be less than the interest on the extra outlay which would be involved in laying the additional mains.

In connection with this subject it will probably be of interest to record what has been done in a few districts in the way of supplying water to villages, hamlets, and scattered cottages therein. What has been done here

may be done elsewhere, and the examples given, showing how certain difficulties have been overcome, may be incentives to others to attempt to do for our rural districts what has already been so well done for our towns.

The Nantwich Rural Sanitary Authority * may fairly claim to be pioneers in carrying water mains through thinly-populated rural districts. They commenced in 1878 by supplying the township of Church Coppenhall, and since then the mains have been extended, until, at the end of 1893, the Authority had supplied, in 32 townships, 2,817 houses, with a population of upwards of 14,000. There are 93 miles of mains, and extensions involving the laying of 27 more miles have been decided upon. "The cottages are supplied with water, pure in quality, plentiful in quantity, and conveniently at hand, with taps within each house, at twopence farthing per week." This payment by the tenants, however, does not cover the whole cost of the supply. The mode in which this is defrayed is thus described by Mr. Davenport, the engineer and surveyor to the district.

"Supposing the cost of a water supply to a township is £1,000, the annual charge upon that amount borrowed from the Public Works Loan Commissioners would be about £60 per annum, which would clear off principal and interest in thirty years. Supposing there are sixty houses to be supplied, the annual cost of furnishing the water, founded upon the average quantity of water consumed per house (as shown in the Authority's statistical tables from actual measurement and cost), would be about £18 per annum, making a total expenditure of £78 per annum. Taking thirty of the houses to bring in 20s. each per annum to the water rate, and the other thirty to bring in 10s. each, which is the minimum, the water rate would only raise £45 per annum, leaving a deficiency against the township of £33 per annum for thirty years.

* "Public Waterworks for Rural Districts." J. A. Davenport, C.E. Surveyor, Nantwich, R.S.D. (*Sanitary Record*, 3rd March, 1894).

By the system of guarantee referred to (a guarantee on the part of the owners of estates benefited, to pay a sum not exceeding 6d. per acre per annum for thirty years), the owners of property step in and pay this, and where either the whole, or a considerable portion of a township, is supplied by these public mains, 1d. in the pound, if needed, is contributed by the general township rate, in reduction of the deficiency. It will make some little difference at first, whether the money is lent to be repaid by equal annual instalments, or annual instalments of principal and interest; in the former case, the instalments being the same each and every year, and in the latter they are rather heavier for the first fifteen years, and lighter for the last fifteen years." This system of guarantee has been very successful in this district, and several landowners have also given considerable amounts for the laying of mains for the benefit of property with which they are connected.

The Maldon Rural District Council have just completed a scheme for supplying eight parishes with water. The total population is only 2,437, spread over an area of 20,000 acres. There are 26 miles of mains. The water is derived from a spring which yields from 60,000 to 100,000 gallons per day of excellent water. The pumping station is near the springs, and the plant consists of two vertical boilers, two horizontal duplex steam pumps so arranged that either boiler will supply steam to either pump. The duty of each pump is to deliver 6,000 gallons of water per hour through a rising main 1,200 yards long into the service reservoir on ground 110 feet above the pumping station. This reservoir is constructed of Portland cement concrete, partly below and partly above the surface of the ground, and supplies the various parishes with water through the 26 miles of mains. Stand posts are fitted at the ends of all the branches, and along the route. They are of the banjo pattern, fitted with self-closing cocks, which can only be opened by a key.

A large proportion of the cottages and farms will be directly connected with the mains. The total cost was close upon £13,000. The district is purely agricultural, and the rateable value is only £5,630. The cottages are supplied with water at a rate of 2d. per week. Most of the farms are supplied by meter. The estimated revenue from water rents and rates is £408 per annum. The balance is raised with the sanitary rate. The whole of the works were designed and carried out by Mr. H. G. Keywood, the Council's Surveyor and Engineer, and admirably exemplify what can be done in a purely rural district.

Similar works of equal magnitude have been in existence some years in the adjoining Rural District of Chelmsford, and every year the mains have to be extended to meet the constantly increasing demand for water. The demand has already become so great that the District Council have acquired an additional spring and connected it with the existing system.

Spring and Ram.—In another small village in one of my districts a spring rising at the outskirts supplies a ram, which pumps water into a tower supported upon iron columns. The tank has a capacity of 1,200 gallons. The water is laid on to several houses and to stand pipes in the street. The total cost was only £200; a portion was raised by subscription, and the remainder paid out of the rates, the payment being extended over three years.

Spring and Steam Pumping.—In another parish, with 321 houses and a population of 1,303, a water supply has been inaugurated which furnishes water to about two-thirds of the population. Over a spring yielding some 30,000 gallons of water per day a covered tank holding 12,000 gallons has been constructed. Upon a brick tower, 70 feet high, a wrought-iron tank holding 15,000 gallons has been fixed. The water is raised from the spring to the tank by a six h.p. engine, through 4-inch suction and rising mains. From the tank it flows through over 2

miles of mains 4-inch, 3-inch, and 2-inch in diameter, to supply the village. The total cost, including the land and spring (which are in an adjoining parish), was slightly over £2,000. The cost of pumping, including wages, is about £45 a year. The loan and interest is being repaid in equal half-yearly instalments, spread over a term of thirty years. An annual sum of £25 is paid for the water supplied to a malt kiln, and a small sum is paid out of the general rate for the water used for road watering, etc.; the balance is raised by a rate of 1s. 4d. in the pound levied on the users of the water.

Spring Water raised by a Water-wheel.—The hamlet of Cressbrook, near Buxton, Derbyshire, has recently been supplied with spring water by pumping, and the following description of the works has been furnished by the engineers, Messrs. J. and J. Webster, of Bridge Street, Buxton:—

"The spring water is conveyed for a distance of 400 yards through 3-inch cast-iron pipes, where it is delivered into a cistern of 120 gallons capacity. The power is obtained for driving the pump with a breast-water wheel, 8 feet diameter by 4 feet wide, constructed of iron and Siemens steel. The driving water* to the wheel is also carried a distance of 400 yards. To the water-wheel is attached a three-cylinder pump, specially designed and constructed by us, to meet the exceeding high pressure (200 lb. per square inch) and give a constant flow. The water is drawn from the above cistern and delivered through 1,125 feet of 3-inch pipe to the reservoir, situated 410 feet higher than the pump. The reservoir has a capacity of 35,000 gallons, and is cut out of the solid limestone rock, which is lined with a wall 2 feet thick, then lined with bricks set in cement, and further grouted between the brickwork and wall with fine, clean gravel and cement. The reservoir is divided into two halves, so that one half can be working whilst the other half is

* Derived from the river Wye.

being cleaned out. The supply to the houses, Cressbrook Hall, and mills is through 3-inch cast-iron gravitation pipes. The taps are enclosed in cast-iron boxes, specially designed to protect them from frost. Provision has been made at the mills to use the water in case of fire. When tested with a hydrant it was found that a stream of water could be thrown about 20 feet higher than the roof of the mills. The total length of pipes is about 2 miles. All the cast-iron pipes are coated by Dr. Angus Smith's process. The quantity of water guaranteed to be delivered into the reservoir is from 3,000 to 4,000 gallons per day, but 12,000 gallons can be delivered without running wheel and pumps at an excessive speed."

The total cost was a little under £1,000, and was borne by the owner of the estate. The water is laid on to 15 stand pipes for the supply of the cottages, and a charge of 1½d. per week is made for the use of the water.

Deep-well Water raised by a Windmill.—At Lechlade, Gloucestershire, a windmill has been successfully used for supplying the village with water. The population is 1,250, and the number of inhabitants supplied about 1,000. The windmill was made by the Ontario Company, and has sails of 18 feet diameter. The pumps are double-action, with 4-inch cylinders. A tank capable of holding 60,000 gallons of water is supported on a brick tower 10 feet high, in which the pumps are placed, and on the top of this is the windmill working a shaft passing through the tanks to the pumps which are directly over the well. The well is a tubular one 4 inches in diameter, driven to a depth of 24 feet through a bed of clay into water-bearing gravel. The windmill has an automatic action, shutting off when the tank is full and collapsing when the wind pressure is beyond that for which the sails are set. The supply has never failed during the four years the works have been in existence, the storage in the tank having proved ample to tide over the calm periods when the pumps were out of action. The water is supplied to

stand pipes in the streets, but any house can have it laid on by paying a rate of 10s. a year. The money was borrowed by the Sanitary Authority and has to be paid off in thirty years. The water rate is 3d. in the pound. Messrs. Johns Brothers, Lechlade Foundry, carried out the scheme, from the designs of Mr. J. H. Bardfield, London. The total cost of the works was £1,800.

Spring Water supplied by Gravitation.—The village of Winfrith, Dorsetshire, has been supplied with water from a spring at the outskirts. The works were designed and carried out by Messrs. Foster, Lott, and Co., of Dorchester. The springhead is situated on the hillside above the rectory farm and close to the Chaldon road. The water springs from the limestone rock, and is not only of organic purity but is remarkably clear and sparkling. It is collected at the very springhead into a perforated iron container, and there have been placed around the outside of the container several hundred loads of flint, gravel, and chalk. There is a 12-inch overflow, the surplus water running into the brook course. The container and chamber are hermetically sealed, and the water is beyond all possible chance of contamination from the foul Chaldon brook, nor can it be intentionally polluted. From the spring the water is conveyed by 4-inch cast-iron pipes into the village, and waste-preventing hydrants of the latest pattern are placed at convenient distances for public use. There is quite an 18 feet head at the spring, and an ample pressure to carry the water many miles farther if required. All the valves are Lambert's high-pressure diaphragm valves, of the same pattern as at the Dorchester Waterworks, as also are the boxes and castings. There is an entire absence of expense after the initial outlay, the water being conveyed by the natural force of gravity to the various deliveries.

Spring Water pumped by a Turbine.—The waterworks at West Lulworth, referred to in Chapter XIX., were also designed and constructed by the same firm. An

attempt to supply West Lulworth with water was made about ten years ago, a spring on the Bindon Hills having been tapped and pipes laid on to various points. This was opened in May, 1886, the whole cost having been borne by the Weld estate; but from the first it was found to be wholly inadequate. The reservoirs and pipes being intact—the former situated on the hillside quite 300 feet above the sea-level—it was suggested that the same plant might be utilised. Attention was directed to the great spring under the rocks close to the cove, and Mr. Foster was consulted. A portion of the water is conveyed from the spring to the old mill-pond on the other side of the road, which has been thoroughly cleared out and now forms quite an ornamental lake, to pump the supply to the reservoirs in the hillside 300 feet above. From the pond the water passes to the top of a new stone tower, which contains a vortex horizontal turbine. The turbine is fixed in the pit at the bottom of the tower, and is 20 feet below the level of the water in the pond. The water falls to the turbine by means of an upright vertical pipe, the waste being taken at the bottom by a 12-inch drain and carried to the sea. From the turbine, which runs about 600 revolutions per minute, the power is communicated by a 10-inch pulley to a large pulley on the over-head shafting, and from thence the power is transferred to a set of high-pressure three-throw plunger pumps. It is estimated that these pumps, driven by the means mentioned, which are equal to five horse-power, will lift 1,200 gallons an hour continuously, and they run with a surprising degree of smoothness and absence of noise or friction. The pumps are fitted with a pressure gauge which not only registers the pressure but the height of the water in the pipes and tanks. Notwithstanding the recent drought, which has had a material effect on the spring, there is quite sufficient water to pump up more than double the quantity that Mr. Foster contracted to deliver at the reservoir. The tower is built of local

stone, and forms quite an ornamental feature in this pretty village. The reservoirs are 120 feet by 20 feet, and will hold 60,000 gallons. Formerly they were uncovered, and not only exposed to the air but to various contaminations. They are now covered with concrete, and trapped and locked in the same way as the spring at Winfrith. Besides making a large number of connections in the village, a set of hydrants and hose for use in case of fire have been provided.

Deep-well Water raised by an Oil Engine.—At a recent gathering of Medical Officers of Health, Dr. Ashby, of Reading, gave a very interesting account of the waterworks recently established for the supply to a village (Sonning) in his district. He stated that the water was derived from a boring in the upper chalk, 75 feet deep, yielding about 70 gallons per minute. The reservoir has a capacity of 35,000 gallons, and the rising main from the well to the reservoir is 4 inches diameter and 1,783 feet in length. The main enters the top of the reservoir at about 100 feet above the level of the water in the bore-hole. The reservoir is about 4,000 feet from the commencement of Sonning village, its bottom being about 48 feet above the highest, and 83 feet above the lowest parts of the village. The distributing mains consist of 4,390 feet of 4-inch pipe and 3,935 feet of 3-inch pipe. There are sixteen hydrants, five air-valves, and seven sluice-valves, besides one on the draw-off pipe at the reservoir. The engine-house cost £124, the engine and pumps £260, the tube well £73, making a total of about £457 for the entire pumping station and well. The total cost of the works was £1,840. With the sanction of the Local Government Board £1,800 was borrowed; of that sum £400 has to be repaid in fifteen years and £1,400 in thirty years. To repay the annual instalments of principal and interest, and to cover the cost of pumping and other expenses, a rate of 1s. in the pound on houses

and 3d. on land is required, besides the water rate charged on the occupiers of premises actually supplied. The charges for domestic supplies are 7s. a year for all houses under £14 rateable value, and $2\frac{1}{2}$ per cent. on the rateable value of all other houses, and some extra charges for farmyards, cowkeeping, and livery stables. The expense is considerable, but, as Dr. Ashby remarks, "it would have cost but little more to have supplied a considerably larger place." Sonning has a population of 515 persons, and its rateable value is £4,398. The oil engine is of two brake horse-power, and the pumps are a set of treble ram pumps, with gun metal plungers 4 inches in diameter by 9 inches stroke. They are fixed to the suction pipe at the top of the lining tube of the bore-hole. Dr. Ashby made a very careful series of observations, showing the capacity of the pumps and the cost of pumping. He says:—

"From 3rd September to 30th September, 1894, we pumped $31\frac{1}{2}$ hours on 11 days. During the whole of that time I was present and took exact observations of all the materials which were consumed. We could have done the pumping in four days, but we pump more frequently in order to keep a good stock of water in the reservoir in case of any fire occurring, or in the event of the machinery requiring any repairs, so that the village may not be without water. We consequently use rather more oil in starting the engine than would be absolutely necessary. In that time the pumps made 57,397 revolutions, an average of 1,822.1 an hour. There are 7.2 revolutions of the engine to 1 revolution of the pumps, so the engine ran at an average speed of 218.65 revolutions per minute. The total quantity of water raised was 75,764 gallons, or an average of 2,405.2 per hour. The supply per head of the population per day was about 7 gallons.

"The consumption of materials was as under:—

		s.	d.
12 gallons of tea rose oil	at 5d.	5	0
1 battery charge	at 1s.	1	0
$1\frac{1}{2}$ zinc for battery	at 3d.	0	$4\frac{1}{2}$
24 fluid ounces of sulphuric acid . .	at 2d. per lb.	0	$5\frac{1}{2}$
Total cost of material consumed by the engine . .		6	10
$3\frac{1}{2}$ pints of lubricating oil for engine and pumps	at 2s. a gall.	0	$10\frac{1}{2}$
Cotton waste	at 4d. per lb.	0	$3\frac{1}{2}$
Total cost of materials consumed by engine and pumps		8	0
Cost of materials for engine per 1,000 gallons of water raised 100 feet high	1·082 penny		
Total cost of materials for engine and pumps per 1,000 gallons of water raised 100 feet high .	1·267 penny		
Consumption of oil per h.p. per hour . . .	1·5 pint.		

Spring Water pumped by Gas Engine.—Great Baddow and Springfield are two adjoining villages with a population of about 4,000. The waterworks are situated in a piece of ground near the spring. The spring yields 80,000 to 100,000 gallons per day. For the past fifteen years one eight horse-power gas (Crossley Otto) engine and set of pumps have been sufficient to raise all the water required; but recently a new seven horse-power (Crossley Otto) engine with a set of three-throw pumps has been erected as a duplicate.

There are four reservoirs 24′ × 12′ × 6′ brick-built and covered with brick arches, each holding 10,350 gallons. The water is pumped twice daily from these reservoirs to a tank holding 40,000 gallons on the top of a tower 96 feet high. The villages are then supplied by gravitation.

The amount of gas used in pumping is 200 feet per hour for the new engine and 250 feet per hour for the old engine. Gas at 3s. 4d. per 1,000 feet. The total expense for working is about £180 per year, exclusive of the cost of repairing mains. The amount of water rents collected from the houses supplied is about £350 per annum. Where water is supplied by meter the charge varies from 1s. 6d. to 1s. per 1,000 gallons, according to the amount consumed.

CHAPTER XXVI.

WATER CHARGES.

A comparison of the charges for water in different places is a difficult matter. In some districts the charges made to the consumers defray the total cost of the water including repayment of principal and interest. In other cases a certain portion of this cost is paid out of the General Sanitary Rate. Where the waterworks are owned by companies the prices charged may or may not include a profit; sometimes the water may even be supplied at a loss.

Occasionally the charges are based on the rental, more frequently on the rateable value. The rateable value is very variable, and consequently where the assessments are low the rates will be correspondingly high, and *vice versâ.*

For domestic purposes water is almost invariably charged at so much per centum on the annual or rateable value; for other purposes the supply is usually by meter. Where the owners of cottage property pay the rate whether the cottages are occupied or not, a reduction of from 10 per cent. to 30 per cent. is generally made.

Meters are almost invariably supplied by the Water Authority and an annual rental (10 per cent. on cost) charged.

It is difficult to define "domestic purposes," but Sec. 12 of the 26 and 27 Vict., cap. 93, enacts as follows: "A supply of water for domestic purposes shall not include

a supply of water for cattle or for horses, or for washing carriages, where such horses or carriages are kept for sale or hire, or by a common carrier, or a supply for any trade, manufacture or business, or for watering gardens, or for fountains or for any ornamental purpose. "In many private Acts there are still more extended definitions of what "domestic purposes" does not include.

Generally water to one water-closet is included in the rate; extra closets being charged at from 5s. to 10s. per annum.

One bath may be allowed and others charged extra, or a single bath may be an extra. There is also generally a stipulation that if the bath holds, when filled for use, more than a given amount, usually 40 or 50 gallons, a further charge is made.

I have recently had occasion to prepare for the Essex County Council a list of the charges made by all the Water Authorities in that county, and these are briefly summarised in the subjoined table.

The following typical scales are given in full:—

East London Waterworks Area of Supply.

The East London Company have two scales of charges, one for the Metropolitan area and one for districts outside the metropolis.

In the Metropolitan area the basis is the *Rateable Value*, outside the Metropolis it is the *Net Annual Value*. Otherwise the figures in the two scales are identical.

Outside the Metropolis.

Net Annual Value.		Per Cent. Charge.	Baths.	Water Closets.	High Service. *i.e.*, exceeding 20 Feet above the Pavement.
Not exceeding	£30	5	4s. each	Nil.	25 per cent. in addition.
Exceeding	£30	5	4s. ,,	4s. each	
,,	£50	5	6s. ,,	6s. ,,	
,,	£100	5	8s. ,,	8s. ,,	

The basis to be adopted will be that laid down in the judgment of the House of Lords, namely, "The rent at which the property would let, deducting the probable average annual cost of repairs, insurance, and other expenses (if any) necessary to maintain the premises in a state to command such rent." (Such deductions amount generally to about 10 per cent.) To remove misapprehension consumers are informed that the "Parish Assessment" is not imposed as the basis, and the directors cannot accept it.

The following uses are not included in the charge:—

Steam engines, warming, ventilating machines, apparatus, horses, cattle, washing carriages, gardens, fountains, ornamental purposes, flushing sewers or drains, or for any trade, manufacture, business or pursuit requiring an extra supply of water. With regard to trade purposes a charge is made according to a scale laid down in the Company's Act which varies, according to the quantity of water taken, from 9d. to 6d. per 1000 gallons.

Terms of supply for any of these purposes to be a matter of agreement. No charge is fixed by the Act.

The owners of tenements not exceeding the "annual value" of £20 shall be liable for payment of rates instead of occupiers upon the same scale. See Section 81, East London Water Company's Act, 1853.

Borough of Colchester.

For Domestic Purposes.

	Per Annum £	s.	d.
Where the annual rackrent or value of the premises so supplied does not exceed £5 per annum	0	7	0
Exceeding £5 and not exceeding £10 per annum	0	10	0
,, £10 ,, £15 ,,	0	15	0
,, £15 ,, £20 ,,	1	0	0
,, £20 ,, £25 ,,	1	5	0
,, £25 ,, £30 ,,	1	10	0
,, £30 ,, £40 ,,	2	0	0

Where above £40, at a rate not exceeding £5 per cent. per annum of such annual rackrent or gross value.

Note.—A supply of water for domestic purposes does not include a supply for more than *one* water-closet, or for cattle, or for horses, or for washing carriages where such horses or carriages are kept for sale or hire, or by a common carrier, or for trade or business purposes, or where the same are kept in or upon premises the rent of which is not included with and taken as part of that of a private dwelling house, or are the property of a dealer; or for steam engines: or for railway purposes; or for working any machine or apparatus; or for any trade, manufacture, or business whatsoever; or for watering gardens by means of any tap, tube, pipe, sprinkler, or other such like apparatus; or for flushing sewers or drains; or for public baths; or for any fixed bath, hydrant, lavatory, or urinal; or for any ornamental purpose whatever.

For extra water-closets, each per annum, 5s.
For fixed baths, each per annum, 10s.
For urinals and lavatories, by arrangement.
For fountains, by meter only.

For Gardens.

If a hose or sprinkler be used, the water to be taken by meter at the same rate as is charged for water supplied for trade or business and upon the same conditions.

In the case of detached or market gardens, arrangements to be made with the Superintendent.

		S.	D.	
For one horse	(where chargeable)	2	6	per qr.
For every horse above one	,,	1	6	,,
For carriages, each	,,	1	6	,,
For cows, each	. . . . . .	1	0	,,
For pigs, each	. . . . . .	0	6	,,

For Building Purposes.

	s.	d.	
On entire value or contract price of work for the first £1,000 or part of £1,000 .	5	0	per cent.
For the second £1,000	4	0	,,
For the third and each subsequent £1,000 .	3	0	,,

For slaughter-houses, by meter only.

Water will be supplied by meter by special arrangement.

As to Supplies by Meter.

If water is supplied by meter, it will be by special agreement in each case.

Where water is supplied by meter for both domestic and other purposes a minimum charge will be fixed allowing the consumption of a certain quantity of water. All water beyond that quantity will be charged for as follows:—

Where water is used solely for trade purposes there will be no minimum charge.

	s.	d.	
Up to 50,000 gallons per quarter beyond the quantity allowed by the minimum charge . .	1	2	per 1,000 gallons.
Exceeding 50,000 and not exceeding 100,000	1	1	,,
Exceeding 100,000 and not exceeding 150,000	1	0	,,
Exceeding 150,000 and not exceeding 200,000	0	11	,,
Exceeding 200,000 and not exceeding 250,000	0	10	,,
Exceeding 250,000 and not exceeding 300,000	0	9	,,
Exceeding 300,000 and not exceeding 500,000	0	8	,,
Exceeding 500,000	0	7	,,

The Council will be prepared to supply and keep in repair the meter, at a rent in accordance with the following scale, viz.:—

Size of Meter.	Rate per Quarter. s.	d.
⅜ inch bore	1	6
½ „	1	9
¾ „	2	6
1 „	4	3
1½ „	5	3
2 „	8	0
3 „	11	3
4 „	21	0

In addition to the meter rent in accordance with the above scale, the consumer must bear the expense of all necessary fittings to, and the fixing of, the meter.

Maldon Rural District.

On Sept. 26th, 1900, the District Water Committee controlling the new public supply to Purleigh and other parishes, resolved

1. That a charge be made of 2d. per week for cottages, the annual value of which is £6 and under, for the use of the water.

2. Also that a rate of 1s. 6d. in the £ for 12 months be charged on houses, the annual value of which is above £6.

3. Also that water (other than for domestic purposes) should be supplied by meter, and that consumers requiring meters must provide the same, but obtain them from the Council.

4. Also that where water is taken by meter a minimum charge of 10s. per quarter be made; that up to and including 20,000 gallons a charge of 1s. 3d. per 1,000 gallons, and above that quantity a charge of 1s. per 1,000 gallons be made.

5. Also that a minimum charge of 15s. be made for taking water from swan neck standposts, from the present time until Christmas.

6. Also that owners can obtain keys of standposts from

the Engineer at their own expense, for the use of each cottage, and that in cases where keys have already been distributed, the charge for same is to be requested.

In Southminster where there is a separate public supply the water rate is 1s. 4d. in the pound on the rateable value, and 1s. per 1,000 gallons by meter.

Clacton-on-Sea Urban District.

No. 1.

Ordinary Charges.

Payable quarterly in advance by owners or occupiers of private dwelling houses for the supply of water for domestic purposes only as authorised by 61 and 62 Vict., cap. 185.

	Houses of the Annual Gross Estimated Rental.			Charges per Quarter.		
	£	s.	d.	£	s.	d.
Not exceeding	5	0	0	0	2	2
,,	10	0	0	0	4	0
,,	15	0	0	0	6	0
,,	20	0	0	0	8	0
,,	25	0	0	0	9	9
,,	30	0	0	0	11	6
,,	35	0	0	0	13	3
,,	40	0	0	0	15	0
,,	45	0	0	0	16	6
,,	50	0	0	0	18	0
,,	55	0	0	0	19	6
,,	60	0	0	1	1	0
,,	65	0	0	1	2	3
,,	70	0	0	1	3	6
,,	75	0	0	1	4	9
,,	80	0	0	1	6	0
,,	85	0	0	1	7	0
,,	90	0	0	1	8	0
,,	95	0	0	1	9	0
,,	100	0	0	1	10	0

Where such gross estimated rental shall exceed £100, at a rate per centum not exceeding £5 10s. per annum.

Note.—A supply for domestic purposes does not include a supply of water for cattle, or for horses, or for washing carriages where such horses or carriages are kept for sale or hire, or by a common carrier; nor does it include a supply of water for any trade, manufacture or business whatsoever, or for watering gardens, or for fountains, greenhouses, or vineries, nor for watering roads or pavements, nor for any ornamental purpose, nor for the purpose of washing the fronts or windows of houses, or other buildings, by means of any gutta percha, india rubber, or other tubes or pipes, nor for any of the special purposes for which additional charges are notified in the Table No. 2.

Every supply for domestic purposes includes a supply to one water-closet free of charge; for each water-closet beyond the first included in such domestic supply, an additional charge of 1s. 10½d. per closet per quarter will be made.

Baths.—Each supply to a private fixed bath will be charged the additional sum of 2s. 6d. per quarter, but no bath will be permitted which contains, when filled for use, more than 50 gallons of water.

Where an outbuilding is appurtenant to, or taken with, a dwelling, the charge for water will be on the aggregate annual value of the whole premises, and no deduction will be made by reason of any portion being unoccupied.

Terms of Payment.

For all houses of or under the value of £10 the owners are required to pay for the supply of water, 61 and 62 Vict., cap. 185.

Owners may compound for groups of houses of the above description not being fewer than three in number, and will be allowed a deduction of 20 per cent.; but the owners of such houses will have to pay whether such houses be occupied or not.

All rates, additional charges, charges under agreements, and rents of meters are payable quarterly in advance and

accrue due at the usual quarter-day, viz.: Christmas Day, Lady Day, Midsummer Day, and Michaelmas Day.

The first payment becomes due at the time when the pipe by which the water is supplied is made to communicate with the consumer's pipes, or at the time when the agreement to take water from the Council is made.

The Council reserve to themselves the right of modifying the above stipulations in favour of the consumer. In all cases notice in writing will be required from those intending to discontinue taking a supply of water; and should this notice be given at any other time than on one of the above-mentioned quarter-days, or in the absence of such notice, the consumer must pay the full rates and charges up to quarter-day next ensuing after the date upon which such notice is given, or upon which such discontinuation of supply took effect (10 and 11 Vict., cap. 17).

No. 2.

Additional Charges.

Payable quarterly for supply of water for the following special purpose, viz.:—

	Per Quarter. s.	d.
Carriages with 2 wheels	2	0
,, 4 ,,	3	0
Horses, each	2	6
Cows, not exceeding 2	3	0
,, ,, 4	5	6
,, ,, 6	8	0
Laundresses, upwards from	2	6
Butchers	3	0
Bakers	2	0
Fishmongers	3	0
Gardens attached to a house and included in the gross estimated rental, if watered by hose, to be charged by meter.		
Lock-up shops, offices and warehouses, by agreement.		
Lock-up shops, offices and warehouses will be charged in addition for each water-closet	1	6
Urinals	1	10½

All other purposes not particularly named herein to be charged by special agreement.

No. 3.

Meter Supplies.

(Allowed only in special cases, and at the option of the Council.)

Charges for Water delivered through Meter.

For trade and special purposes, payable quarterly, at the following rates; a minimum quantity of 10,000 gallons per quarter being charged for in any case:—

Quantity used per Quarter.	Gallons.	Price per 1,000 Gals. S.	D.
For the first	50,000 and under	2	3
For the quantity from . .	50,000 to 100,000	2	0
,, ,, . .	100,000 to 150,000	1	9
,, above . .	150,000	1	6

Larger quantities by special agreement.

Hire of Meters.

The Council will provide, fix and maintain the meters, charging a quarterly rent for their use according to size of meter, viz.:—

	S.	D.		S.	D.
For a $\frac{3}{8}$ in. meter .	1	6	For a $1\frac{1}{4}$ in. meter .	3	0
,, $\frac{1}{2}$,, .	1	6	,, $1\frac{1}{2}$,, .	3	6
,, $\frac{3}{4}$,, .	2	0	,, 2 ,, .	4	6
,, 1 ,, .	2	6			

County of Essex.

Table of Annual Water Charges.

District.	Basis of Charge.	Under £5.	£5 to £10.	Over £10.	Water Closets.	
					One.	Each Additional.
Braintree Urban	Rateable Value	5 %	5 %	5 %	...	...
Burnham Urban	,,	5 %	5 %	5 %	...	...
Brightlingsea Urban	,,	8/8	7½ %	7 to 6 %	..	5/-
Chelmsford Borough	,,	Varies from	9d. to 1/-	in £	...	Extra
Clacton Urban	Gross Rental	8/8	8 %	7½ to 6 %	...	7/6
Colchester Borough	Rackrent	7/-	10/-	7½ to 5 %	...	5/-
East London Water Co.	Net Annual Value	5 %	5 %	5 %	...	...
Halstead Urban	Rateable Value	5 %	5 %	5 %	..	...
Herts and Essex Co.	Rackrental	8/8	6 % over	£7 10/-	...	10/-
Maldon Borough	Rateable Value	10/-	7½ %	7½ %	2/-	5/-
Southend Co.	Annual Rental	8/8	7½ %	7½ to 6 %	...	5/-
Stanstead Co.	Rateable Value	6/-	8/- to 10/-	7½ to 6 %	5/-	5/-
Tendring Co.	Rackrent	10/-	16/-	12 to 6 %	...	7/6
Shoeburyness Urban	Annual Value	8/8	7½ %	7½ to 6 %	...	5/-
South Essex Co.	,,	7½ %	7½ %	7½ to 6 %	...	5/-
Saffron Walden Borough	Rateable Value	6/-	6 %	6 %	...	...

District.	Baths.		By Meter per 1,000 Gallons.	Building Purposes.	Extra Charges.
	One.	Each Additional.			
Braintree Urban	...	..	1/-	..	Outside district by meter, 2/- per [1000 galls.
Burnham Urban		...	..	.	....
Brightlingsea Urban	10/- Extra if	over 50 galls.	..	...	......
Chelmsford Borough	...	Extra	1/6	5 % on estimated annual value	......
Clacton Urban	10/-	...	2/3 to 1/6	...	*Vide* copy of scale of charges.
Colchester Borough	10/-	.	1/2 to 7d.	3/- to 5/- %	,, ,,
East London Water Co.	4/-	.	9d. to 6d.	...	25 % extra for high service.
Halstead Urban	...	...	1/-	...	8/- for each horse, 6d. per rod of garden over 6 rods.
Herts and Essex Co.	£1	£1	1/6, or less for large supplies	...	......
Maldon Borough	6/- not more	than 40 galls.	2/ to 1/6	5/- % on contract	2/- each pig, 4/- each cow, 6/- to 8/- each horse.
Southend Co.	10/-	...	2/6 to 1/6, 1/- for	municipal purposes	......
Stanstead Co.	10/-	..	.		8/- for each horse or cow, 4/- for each carriage or cart.
Tendring Co.	10/- not more	than 50 galls.	2 6 to 1/-	.	.....
Shoeburyness Urban	10/-	...	...	..	......
South Essex Co.	10/-	5/-	2/- to 9d.	...	Extra for high pressure, but about to be abolished
Saffron Walden Borough	...	...	1/2 to 1/0½	..	Public houses with yards 50 % [extra.

APPENDIX TO CHAPTER XXVI.

Table of Rates Charged for Domestic Supply of Water in various Towns.

Name of Town.	Charge in the Pound for Domestic Purposes on House £15 Rateable Value.	Source of Supply, etc.	Name of Town.	Charge in the Pound for Domestic Purposes on House £15 Rateable Value.	Source of Supply, etc.
	s. d.			*s. d.*	
Ashton-under-Lyne	*1 10	Surface water. Deficiency, if any, met out of Borough or District Rate.	Liverpool . .	0 $7\frac{1}{2}$	Surface water and pumped from wells. A public rate of 6d. in the pound levied.
Barrow-in-Furness	1 0	Surface water impounded and stored in reservoir.	Leicester . .	1 $2\frac{2}{5}$	Surface water impounded in reservoirs and delivered to town by pipes.
Bath . . .	1 0	Springs.			
Birkenhead . .	0 $10\frac{4}{5}$	Pumped from wells.	Leeds . . .	*1 0	Gravitation from river Washburn, near Otley.
Birmingham .	1 $0\frac{4}{5}$	From rivers and deep wells.			
Blackburn . .	1 $7\frac{1}{5}$	Surface water from large gathering grounds.	Macclesfield . .	1 3	Surface water collected in reservoirs.
Bolton . . .	1 $5\frac{3}{5}$	Chiefly from gathering grounds and by gravitation.	Manchester . .	0 9	From surface water and springs. A public rate of 3d. in the pound is also levied.
Brighton . .	0 9	Pumped from wells.			
Burnley . .	1 0	Surface.	Middlesborough .	*1 3	Surface water and pumped from river. When revenue falls short the balance is a charge on the rates.
Bury . . .	1 6	Surface water and springs. No pumping. Power to levy rate, not exceeding 2d. in the pound on owners of property.	Nottingham . .	*1 $1\frac{1}{5}$	Pumped from deep wells.

Bradford	1 6	Surface water. A public rate of 2d. in the pound is also levied.	Northampton	1 6	From deep wells and surface.
			Oldham	1 6	Surface water.
Cardiff	1 $2\frac{2}{5}$	Gravitation and pumping.	Plymouth	0 $9\frac{1}{2}$	Surface water collected.
Carlisle	*0 $9\frac{1}{5}$	Pumped from river.	Preston	1 $0\frac{2}{3}$	Surface water from gathering ground (no pumping).
Chester	1 8	Pumped from the river Dee.			
Cheltenham	*1 $2\frac{2}{5}$	Springs on the hills. Supply by gravitation.	Rochdale	2 0	Surface water. Deficiency charged on Borough Fund. Last year required a rate of 1s. $1\frac{1}{2}$d. in the pound to meet it.
Darlington	1 $3\frac{1}{5}$	From river Tees.			
Derby	*1 $1\frac{1}{3}$	Chiefly springs.			
Dewsbury	*1 $0\frac{4}{5}$	From reservoirs at Dunford Bridge. A public rate of 3d. in the pound is also levied.	Sheffield	1 4	Surface water from upland gathering grounds.
			Scarborough	1 2	Pumped from wells.
Doncaster	*1 6	By gravitation from reservoirs.	Southport	*1 $1\frac{1}{5}$	Pumped from wells in sandstone.
Dudley	1 3	Pumped from wells in sandstone.	St. Helens	*0 $10\frac{1}{2}$	Pumped from wells sunk in red sandstone.
Exeter	1 0	The river Exe. Water pumped from filter tank. Surplus annually applied in reduction of General District Rate.	Swansea	1 $1\frac{1}{5}$	Surface water and rivers. Any deficiency in Waterworks Revenue is made good out of the General District Rates.
Gateshead	1 4	Surface water.	Wakefield	*1 3	Gravitation. In addition a public rate of 2s. 2d. in the pound is levied.
Halifax	1 4	Surface water.			
Huddersfield	*1 11	Surface water.			
Hull	1 0	Pumped from springs.	Wolverhampton	1 3	Chiefly pumped from wells in sandstone, and part from river.
Keighley	1 6	Surface water. A rate of 2d. in the pound levied.			
Lancaster	1 0	Springs and gravitation.			

* Charged on gross rental.

The information in the above table was obtained from the various towns in April, 1889, and published in the Wolverhampton Corporation Waterworks Report for March, 1892.

GENERAL INDEX.